Indian Institute of Technology Jodhpur

2nd year B.Tech Electrical Engineering Curriculum Structure August 2020

॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

2nd year B.Tech Electrical Engineering
Curriculum Structure

1. Introduction

The vision of the Department is to develop a world class teaching and research atmosphere by excelling in fundamental knowledge and applications of Electrical Engineering through curricular and co-curricular activities. In line with this vision, the department offers an undergraduate program to attract highly motivated students who are interested in cutting-edge technologies in the broad discipline of electrical engineering, and wish for a flexible program to consider a variety of career paths through capability-linked specializations of their choice.

The program provides strong fundamentals in mathematics and science which develop analytical thinking and form the basis of the diverse tool set used by electrical engineers to innovate, design and develop the technology of the future. The engineering design component is integrated throughout the curriculum, motivating and familiarizing students with the real-world engineering challenges and equipping them with the essential technical skills for problem solving. The early strong theoretical foundations and hand-on exposure are supplemented by the core electrical engineering concepts ranging from circuit analysis and design, computing, control, communication, signal processing, and power engineering. Additional problem-solving skills and practical experience are developed through design projects and laboratory experiments.

The curriculum offers flexibility to students for pursuing capability-linked specializations of their choice. The department specializations are designed to enable students to lead technological innovations addressing the emerging industrial and societal challenges in various domains of electrical engineering. The EE students can opt for any one of the departmental specializations in *Cyber Physical Systems, Intelligent Communication and Networking, Communication Engineering, VLSI Systems, Visual Computing, Socio-Digital Reality, Nano and Flexible Electronics, Smart Grid, and Artificial Intelligence of Things*. The in-depth understanding and technical skills acquired through these specializations will enable graduates to play a vital role in advancement of technologies such as 5G/6G communications, smart cities, smart healthcare, and Industry 4.0.

Another distinct feature of the curriculum is provision for minors in *Entrepreneurship* or *Management* or interdisciplinary specializations in *Smart Healthcare*, *Artificial Intelligence*, and *Robotics and Mobility Systems* that allow students to pursue diverse career goals. Students will also have an opportunity to opt for a B. Tech. - Master's dual degree in their chosen specialization or minor area. The curriculum also offers numerous options that enable students to gain industrial experience through collaborative industrial projects at industries and entrepreneurship experience at the Institute's incubation centre.

2. Objectives of the program

The program aims at imparting theoretical foundations and practical skills of electrical engineering discipline. It prepares graduates for three potential career paths:

1. An industrial path to take up the role of a technical leader or a manager through life-long learning.
2. An entrepreneurial path to apply the acquired knowledge to develop new products and initiate Deep Tech Start-up Company.
3. An academic path to enter a top-tier graduate program to conduct cutting-edge research with broad applications, and eventually to pursue a research or academic profession.

3. Expected Graduate Attributes

Graduates of the UG program in EE are expected to have following attributes:

1. Strong understanding of fundamentals of mathematics, science and engineering with emphasis on electrical technologies for Communication, Signal Processing, Devices & Circuits, Computing Systems, Control Engineering, and Power Engineering
2. Ability to apply technical skills to identify, formulate, and solve complex problems encountered in modern electrical engineering practices.
3. Ability to model, analyze, design and experimentally evaluate electrical components or systems that achieve desired technical specifications, subject to certain resource constraints.

4. Ability to compete effectively in a world of rapid technological advancements and assume leadership roles within academic, industrial, or entrepreneurial environments in the broad context of electrical engineering.
5. Have established the foundations for critical thinking that are needed to broaden their careers in diverse disciplines through minor/ graduate-level studies and the process of life-long learning.
6. Ability to recognize and practice professional ethics in working environment.
7. Ability to acquire new knowledge and integrate it in the existing paradigm so as to create new innovative electrical systems for the current and future usage and apply it as needed.

4. Learning Outcomes

The graduates of EE UG program will be able:

1. To acquire knowledge of electrical engineering principles along with the required understanding of computing, engineering fundamentals, mathematics, and science.
2. To apply the concepts of mathematics, sciences and engineering (including computing science) to analyze and design complex electrical and electronic circuits and systems containing hardware and software modules.
3. To gain in-depth understanding of concepts of Signals, Devices, Circuits, Systems, Machine Learning, Programming, Control, Communications, Hardware Design and related interdisciplinary topics.
4. To create, select, and apply appropriate techniques, resources, electrical engineering design and computing tools to solve complex engineering problems with an understanding of the limitations through laboratory exercises and design projects.
5. To perform literature review and patent landscaping for innovative research.
6. To adapt to work in multidisciplinary environment.
7. To understand professional ethics and social responsibilities.
8. To develop technical presentation skills and communicate effectively.
9. To engage in independent learning in the context of technological advancements.
10. To conduct develop attitude for product design and entrepreneurial activities.

5. New skill sets targeted

EE students explore subjects critical to advancement in today's needs — from circuit design and electronics to computing, control and communication, and machine learning. The acquired knowledge will be helpful in future technologies including:

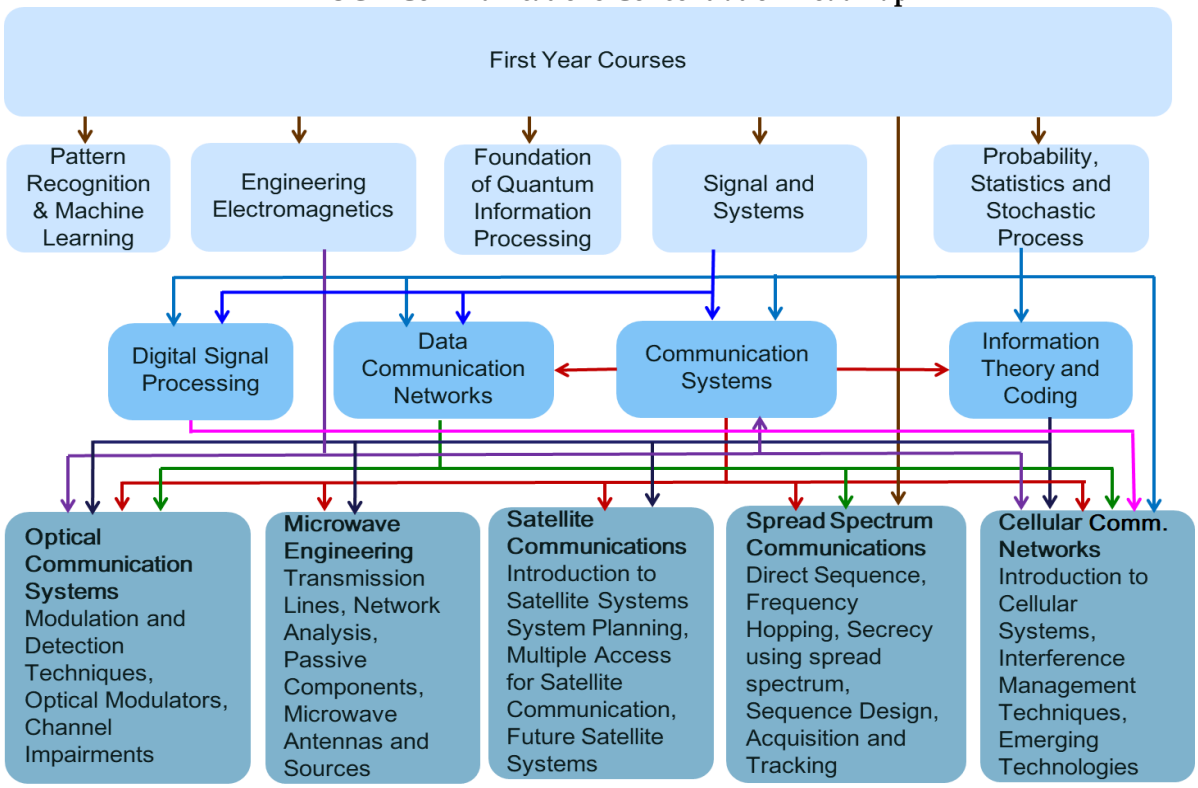
1. 5G and Beyond Communications
2. Cyber Physical Systems
3. Nano-electronics and Quantum Devices
4. Smart Grid

6. Topic clouds and Mapping of Topic clouds with proposed courses

Table 1. Topics and Mapping of Topic with Courses

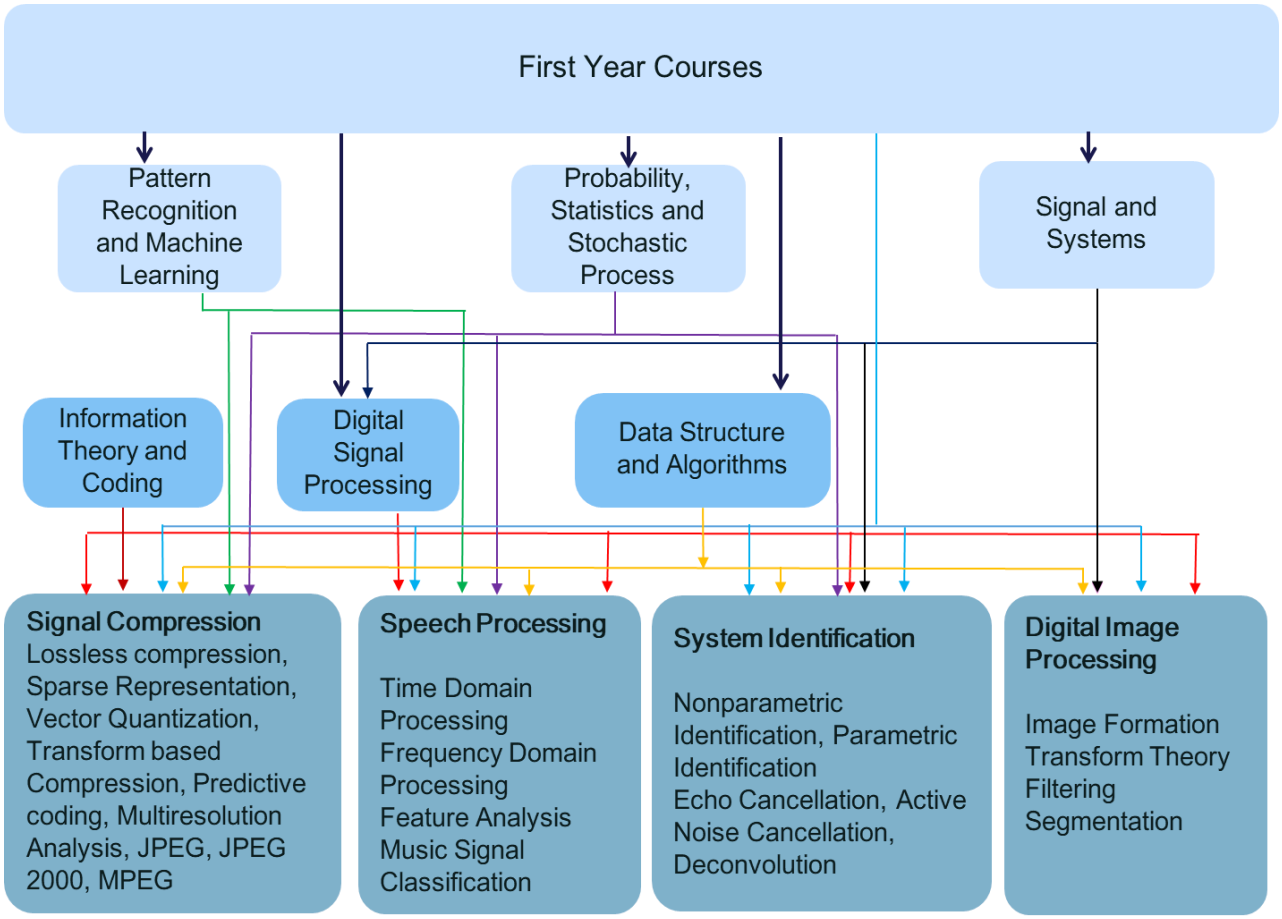
Area	Category	Topics	Course (IE/IS/PC/PE)
Communication	Core	Random Variables, Stochastic Processes, Stationarity, Ergodicity, Discrete and Continuous Random Processes	Probability, Statistics and Stochastic Processes (IE, MA)
		Signal and System Classification, LTI Systems Properties and Response, Fourier, Laplace and z-Transform, Sampling	Signals and Systems (IE, EE)
		EM Wave Propagation, Transmission Lines, Waveguides and Antennas	Engineering Electromagnetics (PC)
		Modelling of Noise and Channels, Noise through LTI Systems, Modulation, Digital Baseband and Passband Transmissions,	Communication Systems (PC)
	Techniques	OSI Architecture, Source Coding, Error correction techniques, Queuing Theory, Switching Techniques, Controlled and Random Access, Routing, End-to-End Reliability	Data Communication Networks (PC)
		Quantization, Discrete Fourier Transform, Fast Fourier Transform, Circular Convolution, Multirate Signal Processing	Digital Signal Processing (PC)
		Source Coding, Channel Coding, Channel Capacity Theorem, AWGN Channel Capacity, Multiuser Channel Capacity	Information Theory and Coding (PE)
	Systems	5G and beyond Communications	Cellular Communication Networks (PE)
			Spread Spectrum Communications (PE)
			Satellite Communications (PE)
			Microwave Engineering (PE)
			Computer Networks (PE)
			Optical Communication Systems (PE)

EE UG – Communications Concentration Roadmap



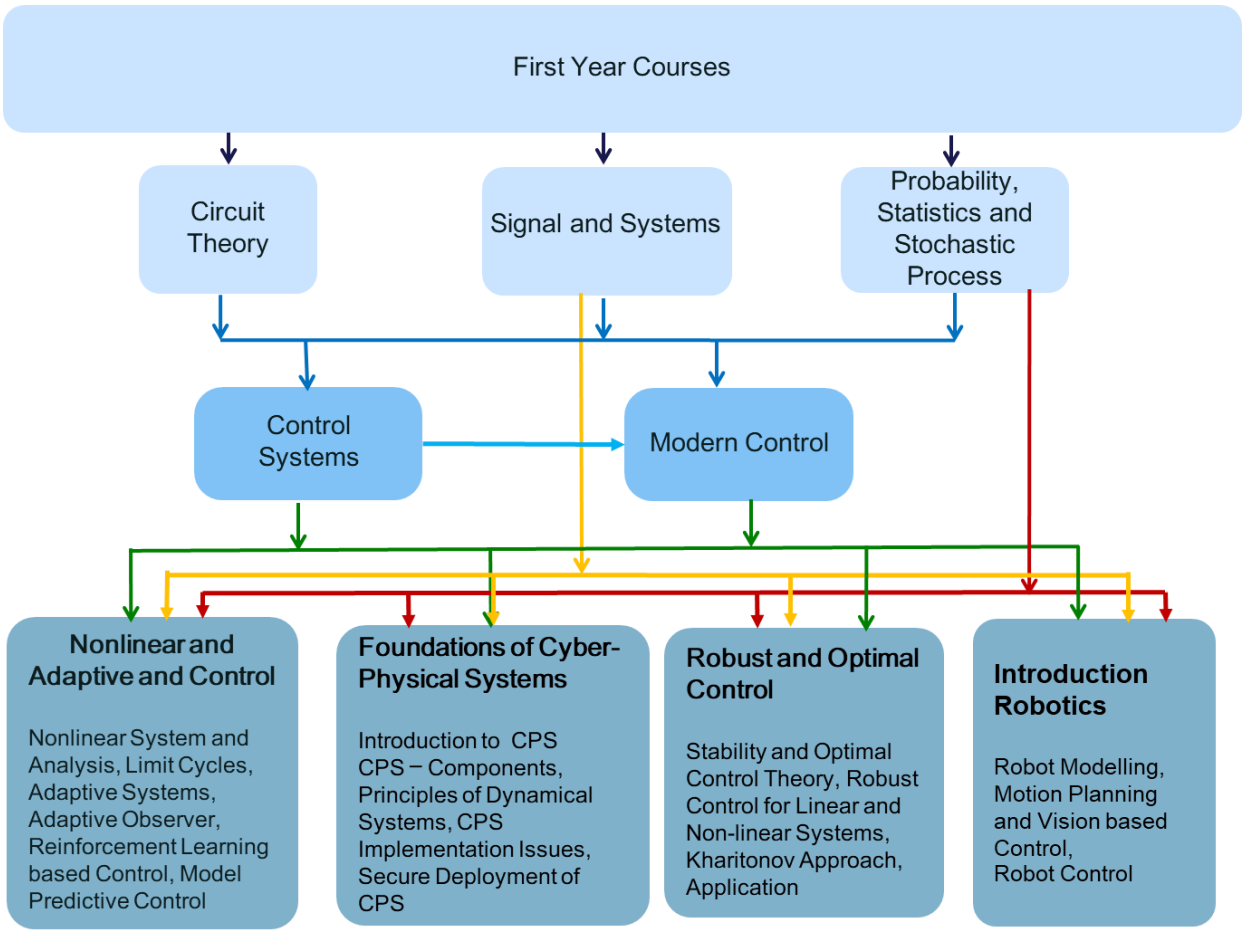
Area	Category	Topics	Course (IE/IS/PC/PE)
Signal Processing	Core	Probability, Random Variables, Concentration bounds, Linear Prediction, Covariance Matrix, Random Processes,	Probability, Statistics and Stochastic Processes (IE, MA)
		Signal Transforms, Signals through LTI Systems, Sampling and Quantization	Signals and Systems (IE, EE)
		Basics of Complexity Analysis, Data Structures, Sorting, Searching, Shortest Paths.	Data Structures and Algorithms (PC)
	Techniques	Sampling and Reconstruction, Fourier Analysis (CTFT, DTFT), Discrete Fourier Transform, Quantization Error Analysis, Finite Length Effects, FIR and IIR Filter Design and Implementation, Multi-rate Systems	Digital Signal processing (PC)
		Shannon's lossless source coding theorem and rate-distortion theory	Information Theory and Coding (PE)
	Systems	Signal Processing and Interpretation	Signal Compression (PE)
			Speech Processing (PE)
			System Identification (PE)
			Digital Image Processing (PE)

EE UG – Signal Processing Concentration Roadmap



Area	Category	Topics	Course (IE/IS/PC/PE)
Control Engineering	Core	Signals Through LTI Systems Fourier, Laplace and z-Transform Systems Modelling in Time and Frequency Domain	Signals and Systems (IE), Circuit Theory (PC)
		Classical Control Theory, Characteristics of Feedback Systems, State-Space Analysis, Controller and Observer Design, Compensation Techniques	Control System (PC)
	Techniques	Vector spaces and Linear operators, State Feedback for MIMO and SISO systems, Discrete time system, Linear system stability, Controllability, observability, reachability and stabilizability, Reduced order observer design, Separation principle	Modern Control (PE)
	Systems	Cyber-Physical Systems	Nonlinear and Adaptive Control (PE)
			Robust and Optimal Control (PE)
			Foundations of Cyber-Physical Systems (PE)
			Introduction to Robotics (PE)

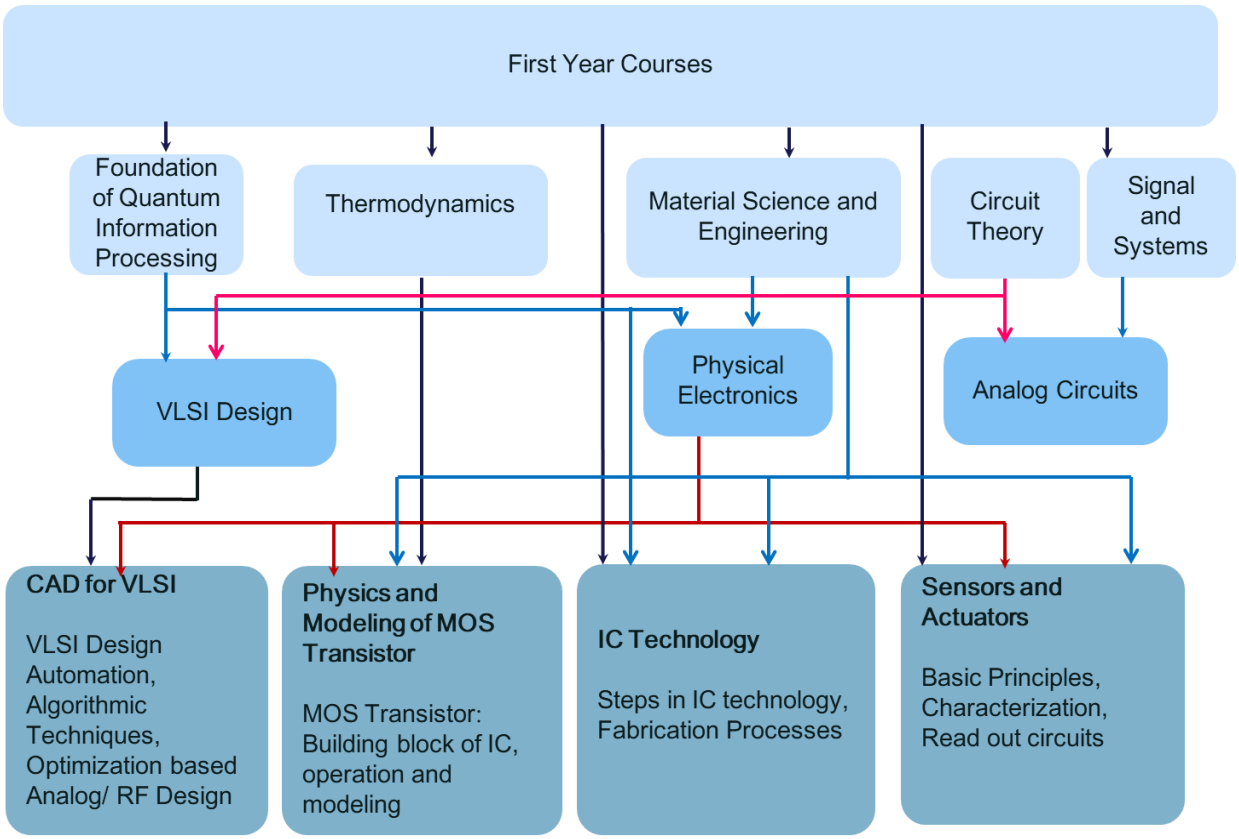
EE UG – Control Engineering Concentration Roadmap



Area	Category	Topics	Course (IE/IS/PC/PE)
Devices and Circuits	Core	Quantum Mechanical Tunneling Bulk vs Quantum Properties Crystals and Energy Bands	Foundations of Quantum Information Processing (IE, PH)
		Magnetic Materials	Material Science and Engineering (IE)
		Heat Transfer	Thermodynamics (IE, ME)
		Fourier Analysis	Signals and Systems (IE, EE)
		Basic Circuit Theory	Circuit Theory (PC)
		Transmission Lines and Guiding Structures	Engineering Electromagnetics (PC)
	Techniques	Energy Band Formation, Drift and Diffusion, Device Physics, MOS Capacitors and Transistors, High Power Devices, Unconventional Devices	Physical Electronics (PC)
		Review of MOSFETs, Single Stage and Differential Amplifiers , Cascade and Cascode Amplifiers, Operational Amplifiers and Feedback, Small Signal and Frequency Response	Analog Circuits (PC)
		ASIC Design Flow, CMOS Implementation of Gates, Combinational and Sequential Circuits,	VLSI Design (PE)

		Static Timing Analysis, Floor planning and Routing, Packaging	
	Systems	Nano-electronics and Integrated Circuits	Integrated Circuit Technology (PE)
			Sensors and Actuators (PE)
			CAD for VLSI(PE)
			Physics and Modeling of MOS Transistor (PE)

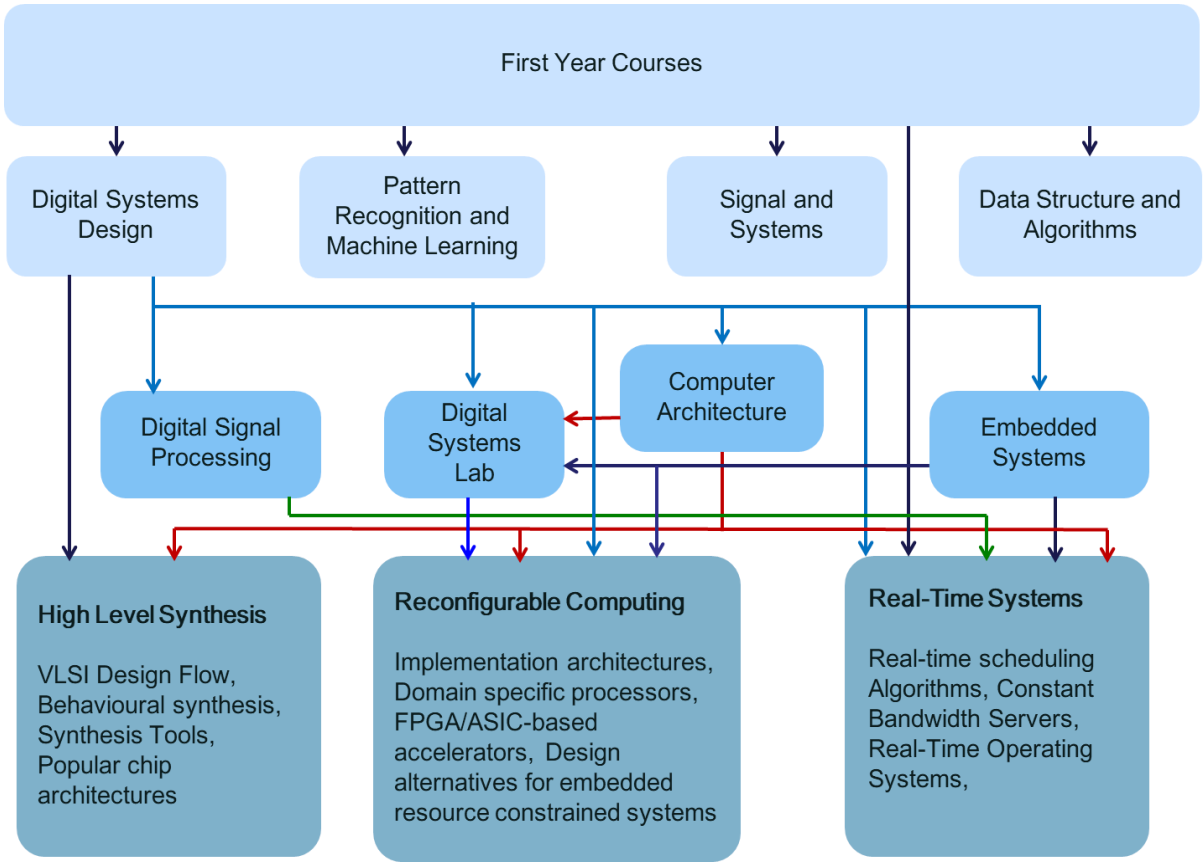
EE UG – Devices and Circuits Concentration Roadmap



Area	Category	Topics	Course (IE/IS/PC/PE)
Computing Systems	Core	Probability, Random Variables, Concentration bounds, Linear Prediction, Covariance Matrix,	Probability, Statistics and Stochastic Processes (IE, MA)
		Signal Transforms, Signals through LTI Systems, Sampling and Quantization	Signals and Systems (IE, EE)
		Design of Digital Circuits Implementation using Verilog/HDL	Digital Design (PC)
		Basics of Complexity Analysis, Data Structures, Sorting, Searching, Shortest Paths	Data Structure and Algorithms (PC)
		Learning methods	Pattern Recognition and Machine Learning (IE)
	Techniques	Pipelined Processing, Memory Organization, Interfacing	Computer Architecture (PC)

		Sampling Theory and Signal Reconstruction, Fast Fourier Transform, Digital Filters	Digital Signal Processing (PC)
		Microprocessors and Microcontrollers, Memory Interfacing, Arm Mbed	Embedded Systems (PC)
		Interfacing with GPIOs, Interfacing DC Motor, Keyboard Interfacing, Use of Timers to produce delay, Implementation of Digital Filters	Digital Systems Lab (PC)
	Systems	Embedded Computing and SoC	High Level Synthesis (PE, CS)
			Real-Time Systems (PE)
			Reconfigurable Computing (PE)
			Artificial Intelligence(PE, AI)
			Pervasive and Mobile Computing (PE, CS)

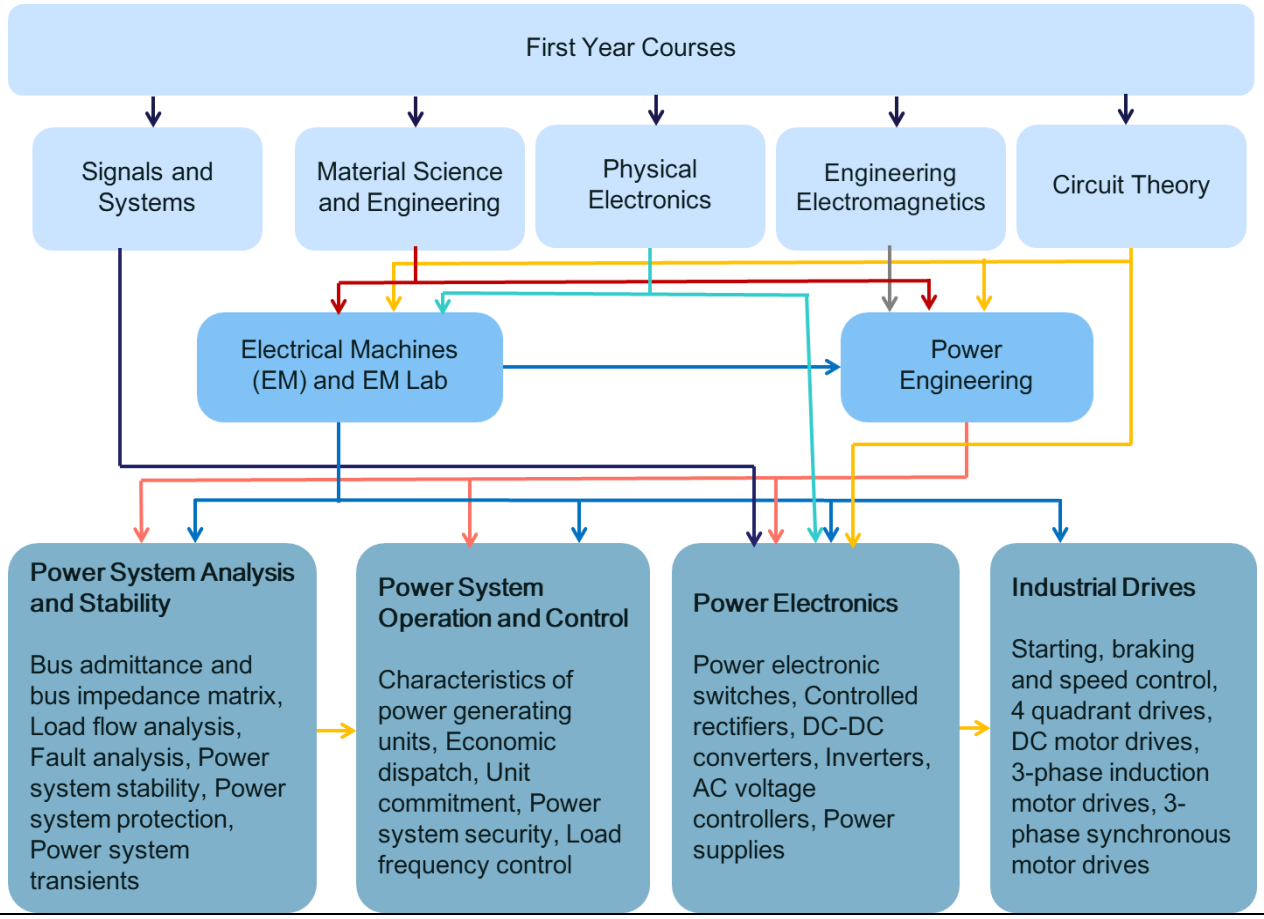
EE UG – Computing Systems Concentration Roadmap



Area	Category	Topics	Course (IE/IS/PC/PE)
Power Engineering	Core	Signal Transforms, Signals through LTI Systems, Sampling and Quantization	Signals and Systems (IE)
		Network theorems, Step and impulse response, Two-port network analysis, Three phase circuits	Circuit Theory (PC)
		Maxwell's equations, Wave propagation	Engineering Electromagnetics (PC)
		Thyristor, IGBT	Physical Electronics (PC)

	Techniques	Transformers, DC machines, Induction machines, Synchronous machines Control of machines using converters	Electrical Machines (PC) Electrical Machines Lab (PC)
		Transmission line modelling and performance, Per-unit representation of power system, Underground cables, Overhead line insulators, Power electronic converter based, compensation, Integration of renewable energy sources, Power system monitoring and protection	Power Engineering (PC)
	Systems	Smart Grid	Measurement and Instrumentation (PE)
			Power System Analysis and Stability (PE)
			Power System Operation and Control (PE)
			Power Electronics (PE)
			Industrial Drives (PE)

EE UG – Power Engineering Concentration Roadmap



7. Course Categories, credit distribution and Credit Structure of B.Tech. Programmes

Table 2. ProposedCourse Categories and credit distribution in the proposed B.Tech. Programmes

S.N.	Course Type	Course Category	Regular B.Tech.	
			Credit	Total
1	Institute Core (I)	Engineering (IE)	**34**	**69**
		Science (IS)	16	
		Humanities (IH)	12	
2	Programme Linked (L)	Science (LS)	7	
3	Programme Core (P)	Programme Compulsory (PC)	**52**	**71**
		Programme Electives (PE)	**16**	
		B.Tech. Project (PP)	3	
4	Open (O)	Open Electives (OE)	10	**10**
5	Engineering Science (E)	Engineering Science Core (EC)	0	**0**
		Engineering Science Elective (EE)	0	**0**
			Total Graded	**150**
6	Non-Graded (N)	Humanities (NH)	6	**15**
		Engineering (NE)	3	
		Design/Practical Experience (ND)	6	
			Total Graded + Non-Graded	**165**

8. Credit Structure of B.Tech. Programmes

Table 4. Credit Structure for B.Tech. Programmes (Up to 6XXX Level)

Type	L-T-P	Distribution of contact and beyond contact hours			Total Credits (TC=TH/3)
		Contact Hours (CH)	Beyond Contact Hours (BCH)	Total Hours (TH)	
1 hour of Lecture	1-0-0	1 hr	2 hr	3 hr	1
1 hour of Tutorial	0-1-0	1 hr	2 hr	3hr	1
1 hour of Lab/Project	0-0-1	1 hr	0.5 hr	1.5 hr	0.5

#Contact hour for project refers to the involvement of students in the laboratory, discussion, etc.

9. List of Programme Compulsory Courses

Table 5. Programme Compulsory Courses

Sr. No	Course Name	LTP	Contact Hours	Credit
1	Data Structures and Algorithms	3-0-2	5	4
2	Circuit Theory	3-0-0	3	3
3	Engineering Electromagnetics	3-0-0	3	3
4	Physical Electronics	3-0-0	3	3
5	Digital Design	2-0-2	4	3
6	Analog Circuits	3-0-3	6	4.5
7	Electrical Machines	3-0-0	3	3
8	Communication Systems	3-0-0	3	3
9	Computer Architecture	3-0-0	3	3
10	Control Systems	3-0-3	6	4.5
11	Digital Signal Processing	2-0-0	3	2
12	Data Communication Networks	3-0-0	3	3
13	Power Engineering	3-0-3	6	4.5
14	Embedded Systems	3-0-0	3	3
15	Digital Systems Lab	0-0-3	3	1.5
16	Electrical Machines Lab	0-0-3	3	1.5
17	Communication Systems Lab	0-0-3	3	1.5
			Total	**52**

10. ScanArea-wise Programme Elective Courses

Table 6. Stream-wise Programme Electives Courses

S. No.	Stream	Courses	L-T-P	Credit
1	Communication	Information Theory and Coding (300)	3-0-0	3
		Computer Networks (CS)	3-0-0	3
		Microwave Engineering (400)	3-0-0	3
		Cellular Communication Networks(400)	3-0-0	3
		Satellite Communications (400)	3-0-0	3
		Spread Spectrum Communications(400)	3-0-0	3
		Optical Communication Systems (400)	3-0-0	3
2	Signal Processing	Digital Image Processing (400)	2-0-0	2
		Speech Processing (400)	2-0-0	2
		Signal Compression (400)	2-0-0	2
		System Identification (400)	2-0-0	2
3	Control Engineering	Modern Control (300)	3-0-0	3
		Nonlinear and Adaptive Control (400)	3-0-0	3
		Robust and Optimal Control (400)	3-0-0	3
		Foundations of Cyber Physical Systems (400)	3-0-0	3
		Introduction to Robotics (IDRP)	3-0-0	3
4	Devices and Circuits	VLSI Design (300)	3-0-0	3
		Biosensors (300)	3-0-2	4
		Integrated Circuit Technology (700)	3-0-0	3
		Sensors and Actuators (400)	3-0-0	3
		CAD for VLSI (700)	2-0-2	3
		Physics and Modeling of MOS Transistor (400)	3-0-0	3
5	Computing Systems	Deep Learning (AI)	3-0-0	3
		High Level Synthesis (CS)	3-0-0	3
		Real-Time Systems (400)	3-0-0	3
		Reconfigurable Computing (400)	3-0-0	3
		Pervasive and Mobile Computing (CS)	3-0-0	3
6	Power Engineering	Measurement and Instrumentation (300)	3-0-0	3
		Power System Analysis and Stability (400)	3-0-0	3
		Power System Operation and Control (400)	3-0-0	3
		Power Electronics (400)	3-0-0	3
		Industrial Drives (400)	3-0-0	3

Mini-Project(0-0-6)
Program elective component for 8th semester

Design/Practical Experience (ND)
Options: Three Summer Design Projects (0-0-4) for 2 Credits each or in regular semesters.

11. Specialization to be offered by the department

Table 7. Specialization and courses

<table>
<tr><th>S. No.</th><th>Name of Specialization</th><th colspan="2">Introduction</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Cyber Physical System</td><td colspan="2">In today's world, there is a global interest to study systems that can interact with each other and the surrounding with cooperative objectives, because of the introduction of new and cheap computational and communication resources. Such systems are usually referred to as cyber-physical systems (CPS). Almost, everything around us constitutes a cyber-physical system. For instance, traffic networks, a swarm of unmanned vehicles, smart power distribution networks, etc., are some of the recent technological movements towards automation.

The philosophy of the cyber-physical systems vertical is to familiarize students with the basic building blocks for the analysis and synthesis of such systems, along with hands-on experiments. The theme of this vertical span through the various core subjects ranging from design, control, and computing to safety and security of cyber-physical systems.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td>Introduction to Cyber physical Systems 3-0-0/ Foundation of Cyber Physical Systems* 3-0-0

Security in Cyber Physical Systems 2-0-0

Advanced Control System 3-0-0</td><td>Robust and optimal control 3-0-0
Nonlinear and Adaptive control 3-0-0
Modern Control 3-0-0
Networked Dynamical Systems and Control 3-0-0
Introduction to robotics 3-0-0
Autonomous Systems 3-0-0
Real-Time Systems 3-0-0
Reconfigurable Computing 3-0-0
Artificial Intelligence 3-0-0
Measurement and Instrumentation 3-0-0
Computer Networks 3-0-3
System Identification 3-0-0
Computer Vision 3-0-0
Edge & Fog Computing 3-0-0
Vehicular Ad-Hoc Networks (VANETs) 3-0-0
Introduction to Smart Grid 3-0-0
Smart Manufacturing 1-0-2
Resource Constrained AI 3-0-0
Industry 4.0: Applications in Manufacturing Systems1-0-0
Optimization 1-0-0
Specialization Project 0-0-12</td></tr>
</table>

*If a student does Foundation of CPS, she/he will be exempted from Introduction to CPS course.

<table>
<tr><th>S. No.</th><th>Name of Specialization</th><th>Introduction</th></tr>
<tr><td>2</td><td>Communication Engineering</td><td colspan="2">The fast development of economy and society requires modern and high-performance communications systems that can reliably communicate the massive amount of data originating from various sources including Internet of Things, while still offering acceptable levels of energy consumption, equipment cost and network deployment and operation cost. To achieve these objective communication engineers require a deep mathematical understanding of the trade-offs involved in efficient reliable communication design and circuits and systems for future communication systems.

The core component of the Communication Engineering specialization enables students to face these challenges by focusing on topics involving communication theory, wireless networking and protocol design, security architectures, and system performance analysis. The elective bouquet provides students an opportunity to either gain required depth for graduate level academic programs of their choice or sufficient breadth to expose them to defining technology for future generation communication systems including optical and millimeter wave technologies.

Specialization Core (8 credits)

Optical Communication Systems(3-0-0)

Wireless Communications (3-0-0)

Digital Communications: Hands-on (1-0-2)

Specialization Elective (12 Credits)

Cellular Communication Networks 3-0-0
MIMO Wireless Communications 3-0-0
UAV Assisted Wireless Networks 3-0-0
Spread Spectrum Communications 3-0-0
Network Security 3-0-0
Statistical Decision Theory 2-0-0
Machine Learning for Communications 3-0-0
Advanced Digital Signal Processing 3-0-0
Multi-rate Digital Signal Processing 3-0-0
Adaptive Signal Processing 3-0-0
Quantum Communications 3-0-0
Optical Techniques for Communications 2-0-2
Optical Signal Processing 3-0-0
Optical Fiber Communications 3-0-0
Free Space Optical Communication 3-0-0
Optical Networks 3-0-0
Antenna Engineering 3-0-0
RF Integrated Circuits 3-0-0
Millimeter Wave Technology 3-0-0
RF System Design for Communications 3-0-0
Radar Engineering 3-0-0
Selected Topics in Communication I 1-0-0
Selected Topics in Communication II 2-0-0
Selected Topics in Communication III 3-0-0
Specialization Project 0-0-6</td></tr>
<tr><td>3</td><td>Intelligent Communication and Networking

(EE, AI and CS)</td><td colspan="2">The development of communications has vastly relied on theories and models, from information theory to channel modelling. These traditional approaches are showing serious limitations, especially in view of the increased complexity of communication networks. The advent of 5G is introducing new challenges for mobile communications service providers, and integrating artificial intelligence/machine learning techniques into networks is one way the industry is addressing these complexities. Advances in artificial intelligence, particularly taking advantage of rapidly increasing network and user behavior data, indicates a new technological frontier of communications and networking, not</td></tr>
</table>

<table>
<tr><td></td><td></td><td colspan="2">only in new methodology in systems and network design, but also in new network architecture accommodating machine learning for broader and efficient services.

The main objective of specialization in Intelligent Communication and Networking is to introduce students to new trends, approaches, methods, systems, as well as communication network architectures and application of artificial intelligence and machine learning to address communication network management issues.</td></tr>
<tr><td></td><td></td><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td></td><td></td><td>Design and Analysis of Communication Networks (3-0-2)

Intelligent Radio Networks (3-0-2)</td><td>Computer Networks
Computation Oriented Communications
Machine Learning for Communications
Pervasive and Ubiquitous Computing
Real-Time Communications
Delay Tolerant Networks
Cognitive Internet of Vehicles
Hardware-Aware Communications
Selected Topics in Communication I
Selected Topics in Communication II
Selected Topics in Communication III
Specialization Project 0-0-12</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Visual Computing

(EE, CS, ME and AI)</td><td colspan="2">This specialization is designed to attract highly motivated students who are interested in the signal processing domain with a focus on visual computing. Current and future industry trends indicate increased involvement of visual computing for various automation processes, healthcare, and entertainment. The designed curriculum aims to provide education with excellence in some of the emerging areas which fall under the broad umbrella of visual computing. The curriculum is designed to enable students in choosing a variety of career paths such as intelligent visual computing, industry, and entrepreneurship. Graduates with specialization in visual computing are expected to have the attributes such as strong understanding of fundamentals of Mathematics, Signal Processing, Speech Understanding, Computer Vision, Computer Graphics, Haptics, Multimedia Processing, and AR/VR.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td>Computer Graphics (3-0-0)
Computer Vision (3-0-0)
Visual Computing Lab (0-0-4)</td><td>Computational Imaging
Computational Photography
Video Processing and Analysis
Bio-imaging
Medical Image Analysis
Image Synthesis
Animations
Digital Image Processing
Selected Topic: Advancements in Computer Vision
Selected Topics in Computer Vision
Visual Perception
Real-Time Vision Architectures
Introduction to AR and VR
Introduction to Haptics
Advance Machine Learning
Scalable Machine Learning</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>Compressive Sensing
3D Shape Analysis
Image and Video Forensics
Specialization Project 0-0-6</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">Socio-Digital Reality
(EE, CS and AI)</td><td colspan="2">The ever growing presence of social media and the need for more realistic ways of interacting via the digital world is fuelling novel and exciting industry innovations. Many industrial players (Google, Facebook, Microsoft etc.) have now dedicated centres and futuristic plans in the said area. Hence, this specialization seeks to provide students with fundamental knowledge that will enable them to design and innovate in several related areas within the broad theme of socio-digital reality.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td>Social Network (3-0-0),
Introduction to AR-VR (3-0-0)
Multimodal interface (0-0-4)</td><td>Introduction to Haptics,
Design Process,
Speech Understanding,
Computer Graphics,
Human Computer Interface,
Natural Language Understanding,
Computer Vision,
Image and Video Forensics
Specialization Project 0-0-6</td></tr>
<tr><td rowspan="3">6</td><td rowspan="3">Nano and Flexible Electronics</td><td colspan="2">Semiconductor devices have been at the core for advancement of the current IC industry. Till now, the technology has followed Moore’s law for scaling towards the sub-10 nm era. To accomplish that, various new materials and device structures have found a place in current generation chips. Moreover, various issues related to technology scaling such as quantum mechanical effects have found importance in R&D for new generation devices. In addition, new non-volatile memory technologies have been explored for faster and denser alternatives to conventional Random Access Memories. Moreover, technologies such as Flexible Electronics have emerged as a potential candidate for large area and low cost options for hybrid integration of flexible components.

To train the students in this specialization and cover the essential fundamentals, three core components have been chosen: Quantum Nano-electronics, Flexible and Printed electronics, & Emerging Devices including alternate transistor structures and new non-volatile memory devices. These will provide fundamental understanding of new generation nanoelectronics, related processing, and characterization. The electives will help in shaping the ability of the students to think creatively, provide an in depth cognition and expose them to deliver towards direct applications and also to undertake industry relevant research. A combination of nano and flexible electronics will prepare students for new age challenges such as cost, power, and wider suitability for various applications.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td>Introduction to Spintronics (3-0-0)
Flexible and Printed Electronics (3-0-0)
Advanced Compact Modeling (2-0-0)</td><td>Nano Sensors
Quantum Nano-Electronics
Non-Volatile Memory Technologies</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>Semiconductor Optoelectronics
Organic Optoelectronics
Specialization Project 0-0-12</td></tr>
<tr><td rowspan="3">7</td><td rowspan="3">Artificial Intelligence of Things (AIoT)

(EE, CS and AI)</td><td colspan="2">Artificial Intelligence of Things (AIoT) is a combination of artificial intelligence (AI) technologies with the internet of things (IoT) infrastructure to achieve more efficient IoT operations by enhancing data management and analytics. This is transformational and mutually beneficial for both technologies as AI improves data analytics and decision making capabilities through machine learning and IoT adds value through better connectivity, signalling and data exchange.

The specialization in AIoT is designed to impart knowledge in a wide variety of fields such as IoT, communications, VLSI, computing, AI and ML. Design of IoT system architecture, its components and applications along with machine learning and AI algorithms is covered through courses such as Introduction to IoT and Artificial Intelligence. Industry relevant circuit design practices are included in courses such as Analog and Interfacing Circuits and Digital and SoC Design. The program also features hands-on implementation of IoT systems through labs and tutorials.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td>Artificial Intelligence / Advanced Machine Learning (3-0-0)
Introduction to IoT (1-0-0)
Digital and SoC Design (3-0-0)
SIoT lab (0-0-2)</td><td>Embedded Systems
Microsystems Fabrication Technology
Sensors and Measurements
Deep Learning
Advanced Machine Learning
Advanced Artificial Intelligence
Edge and Fog Computing
Neuromorphic Computing and Design
Analog and Interfacing Circuits
Data Communication and Networking
Resource Constrained AI
Specialization Project 0-0-12</td></tr>
<tr><td rowspan="3">8</td><td rowspan="3">VLSI Systems

(EE and CS)</td><td colspan="2">In the current era of Internet-of-Things (IoT), Artificial Intelligence (AI) and 5G Circuits, there are multiple prototypes being proposed and demonstrated these days for smart and real-time applications. To support this, high-speed circuits/systems are required which should be able to handle high bandwidth requirements of these applications. Over the decades, Very Large Scale Integration (VLSI) technologies have been a robust way to implement the required functionality through digital systems implementation and make it very easy for the designers at different abstraction levels to transfer the intellectual properties. For meeting timing and power requirements in these systems, various aspects of application-specific integrated implementation of digital and analog circuits/systems is required.

This program aims to provide the students an exposure by making them understand the functioning, designing and testing of VLSI Circuits and System as well as their performance assessment criteria. The program includes a variety of detailed courses on Analog Circuits, Digital Circuits, Mixed-Signal Circuits, Synthesis, Verification and Testing. These courses address state-of-the art design methodologies as well as current trends in the industry such as high-speed design issues and techniques.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
</table>

<table>
<tr><td></td><td></td><td>Hardware Design for Artificial Intelligence 3-0-0
Formal Verification 2-0-0
Advanced VLSI Design and Lab 2-0-2</td><td>Digital and SoC Design
Fundamentals of Signal and Power Integrity
Image Sensor Design and Applications
Neuromorphic Computing and Design
VLSI Broadband Communication Circuits
VLSI Testing
Hardware Software Co-Design
Specialization Project 0-0-12</td></tr>
<tr><td rowspan="3">9</td><td rowspan="3">Smart Grid</td><td colspan="2">Society’s ability to utilize more renewable energy like wind and solar power is limited by the fact that our existing energy architecture was designed a century ago. The current system relies on large, centrally controlled power plants with predictable outputs. But wind and solar power fluctuates with environmental conditions, are difficult to control, and the power they generate requires conversion. Adapting the existing grid to operate reliably with renewable energy sources is a complex task. A new architecture for power distribution, called the smart grid, is required to accommodate renewable energy.
New technologies can have transformative impacts on remote communities that are not served by traditional power grids. Power distribution challenges are faced all over the world and the students should have an opportunity to receive training in advances in smart grid technology.</td></tr>
<tr><td>Specialization Core
(8 credits)</td><td>Specialization Elective
(12 Credits)</td></tr>
<tr><td>Introduction to Smart Grid 3-0-0
Renewable Energy Systems 3-0-0
Power Quality 2-0-0</td><td>Power System Protection 3-0-0
Power System Dynamics and Control 3-0-0
HVDC & FACTS 3-0-0
Power Systems Restructuring 3-0-0
Power Quality Mitigation Techniques 3-0-0
Plugin Electric Vehicles 3-0-2
Power System Reliability and Security 3-0-0
Selected Topics in Distributed Generation 3-0-0
Introduction to Cyber-Physical Systems 3-0-0Specialization Project 0-0-6</td></tr>
</table>

12. Curriculum of B.Tech. inElectrical Engineering (Regular)

Cat	*Course*	*LTP*	*CH*	*NC*	*GC*	*Cat*	*Course*	*LTP*	*CH*	*NC*	*GC*
	I Semester						**II Semester**				
IE	Introduction to Electrical Engineering	3-0-2	5	-	4	IE	Engineering Mechanics	2-1-0	3	-	3
IE	Introduction to Computer Science	3-0-2	5	-	4	IS	Chemistry	3-0-0	3	-	3
IE	Introduction to Bioengineering	3-0-2	5	-	4	IS	Physics	3-0-0	3	-	3
						IS	Chemistry Lab	0-0-2	2	-	1
						IS	Physics Lab	0-0-2	2	-	1
IS	Mathematics I	3-1-0	4	-	4	IS	Mathematics II	3-1-0	4	-	4
IE	Engineering Visualization	0-0-2	2	-	1	IE	Engineering Realization	0-0-2	1	-	1
NE	Engineering Design I	0-0-2	2	1	-	NE	Engineering Design II	0-0-2	2	1	-
NH	Communication Skill I	0-0-2	2	1	-	NH	Communication Skill II	0-0-2	2	1	-
NH	Social Connect and responsibilities I	0-0-1	1	0.5	-	NH	Social Connect and responsibilities II	0-0-1	1	0.5	-
NH	Performing Arts I /Sports I	0-0-1	1	0.5	-	NH	Performing Arts II/Sports II	0-0-1	1	0.5	-
	Total	**12-1-14**	**27**	**3**	**17**		**Total**	**11-2-12**	**25**	**3**	**16**
	III Semester						**IV Semester**				
IE	Materials Science & Engineering Fractal 1 – Energy Materials Fractal 2 – Magnetic Materials F3 – Computational Material Design	3 × 1-0-0	3	-	3	IE	Pattern Recognition and Machine Learning	3-0-2	5	-	4
IE	Signals and Systems	3-1-0	4	-	4						
IE	Thermodynamics	3-1-0	4	-	4	PC	Circuit Theory	3-0-0	3	-	3
LS	Probability, Statistics and Stochastic Processes	3-1-0	4	-	4	PC	Engineering Electromagnetics	3-0-0	3	-	3
LS	Foundations of Quantum Information Processing	3-0-0	3	-	3	PC	Digital Design	2-0-2	4		3

PC	Data Structure and Algorithms	3-0-2	5	-	4	PC	Physical Electronics	3-0-0	3		3
NE	Intro. To Profession	0-0-2	2	1		IH	Humanities I	3-0-0	3	-	3
	Total	**18-3-4**	**25**	**1**	**22**		**Total**	**17-0-4**	**21**	**-**	**19**
	V Semester						**VI Semester**				
PC	Analog Circuits	3-0-3	6	-	4.5	PC	Power Engineering	3-0-3	6	-	4.5
PC	Electrical Machines	3-0-0	3	-	3	PC	Digital Signal Processing	2-0-0	3	-	2
PC	Communication Systems	3-0-0	3	-	3	PC	Data Communication Networks	3-0-0	3	-	3
PC	Computer Architecture	3-0-0	3	-	3	PC	Embedded Systems	3-0-0	3	-	3
PC	Control Systems	3-0-3	6	-	4.5	PC	Communication Systems Lab	0-0-3	3	-	1.5
						PC	Digital Systems Lab	0-0-3	3	-	1.5
						PC	Electrical Machines Lab	0-0-3	3	-	1.5
IH	Humanities II	3-0-0	3	-	3	PE	Program/Open Elective	3-0-0	3		3
NH	Professional Ethics I	0-1-0		1	-	NH	Professional Ethics II	0-0-2	2	1	-
	Total	**18-1-6**	**24**	**1**	**21**		**Total**	**15-0-14**	**29**	**1**	**21**
	VII Semester						**VIII Semester**				
PP	B. Tech. Project	0-0-6	6	-	3	IH	Humanities IV	3-0-0	3	-	3
PE / OE	Programme/Open Electives	-	-	-	9	PE / OE	Programme/Open Electives	-	-	-	14
IH	Humanities III	3-0-0	3	-	3						
IS	Environmental Science	2-0-0	2	-	2						
	Total	**15-0-6**	**-**	**-**	**17**		**Total**	**17-0-0**	**-**	**-**	**17**
										Total of Graded Credit	**-** **150**
										Total of Non-Graded Credit	**9** **-**
										Non-Graded Design Credits	**6** **-**
										Grand Total	**165**

14. Detailed Program Compulsory Course Contents

Title	**Physical Electronics**	Number	**EEL2XXX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. EE	Type	Compulsory
Prerequisite	Quantum Mechanics		

Objectives

The Instructor will:

1. Provide background knowledge of basic semiconductor and semiconductor component physics and to use relevant theoretical models for calculating properties and performance of semiconductor materials and components.
2. Make students familiar with handling characterization of semiconductor components and circuits.

Learning Outcomes

The students are expected to have the ability to:

1. Describe the crystal structure and electronic band structure of the most common semiconductor materials, along with calculation of properties of semiconductors and charge transport.
2. Explain the physics of p-n junction, the function and transport characteristics of the p-n diode, the bipolar transistor and the MOSFET transistor
3. Describe metal-semiconductor junctions and semiconductor hetereojunctions and their application in electronic components

Contents

Foundation [8 Lectures]:
Crystal structure, Review of quantum mechanics (3 L);
Electrons in periodic lattices, E-k diagrams, Electrons, holes and phonons. Effective mass, intrinsic & extrinsic semiconductors, free carrier and carrier concentration and Fermi-level (5 L).
Charge Transport [4 Lectures]: Scattering and Drift, Mobility, Hall Effect, excess carriers. Surface recombination, electrostatic field and built-in electric field.
PN junction [7 Lectures]:
Electrostatics, equilibrium and depletion approximation. Reverse bias transition capacitance, breakdown in PN junctions (4L)
PN junction under forward bias, minority carrier injection, DC current-voltage characteristics, Temperature effect (3L)
*Non-ideal diodes [5 Lectures]:*Tunneling diodes, AC Analysis, charge storage and transient characteristics; Schottky barrier diodes,Ohmic contacts, Heterojunctions.
Bipolar transistors [8 Lectures]:
Derivation of I-V and current gain expressions, Equivalent circuits, Frequency response. (4 L);
pnpn structures, Silicon controlled rectifier, thyristor, Gate turn-off thyristor, Insulated-Gate bipolar transistor (4 L).
MOS Structure and Transistors [10 Lectures]:
MOS capacitors, Flatband and threshold voltages (3 L);
Static MOS transistor, I-V Characteristics, MOS transistor equivalent circuit, cutoff frequency (4 L);
Body effect, Short Channel Devices, basic CMOS fabrication (3 L)

Textbook

1. Neamen, D. Biswas, D., (2017), *Semiconductor Physics and Devices*, 4th Edition, McGraw Hill
2. Streetman, B. G., Banerjee S. K., (2015), *Solid State Electronic Devices*, 7th Edition, Pearson Education India

Self Learning Material

1. Solid State Devices, NPTEL Course, Department of Metallurgical & Materials Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117106091/

Title	**Circuit Theory**	Number	**EEL2XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. EE	Type	Foundation course
Prerequisite	Signals and Systems		

Objectives

The Instructor will :

1. Teach the fundamentals of circuit elements and analyses.
2. Teach the time and frequency domain analyses of circuits.
3. Discuss the stability of a network.

Learning Outcomes

The students are expected to have the ability to:

1. Solve different electric circuit problems in time and frequency domain.
2. Analyze various two port networks and their stabilities.

Contents

Review of fundamental circuit elements, sources, and theorems [4 Lectures]: Properties of resistor, capacitor, inductor, and various sources. Discussion and problem solving on KVL, KCL, maximum power transfer theorem, compensation theorem, Thevenin and Norton theorems, Millman's theorem, Miller effect, Tellegen's theorem, graph theory approach of circuit analysis.

*Three phase systems [4 Lectures]:*Three phase voltage and current, star-delta connections, line-to-line and phase quantities, balanced and unbalanced circuits and power measurements.

Two port network analysis and synthesis [6 Lectures]:

Representation of two port networks in terms of impedance (Z) and admittance (Y) parameters, Transmission ($ABCD$) parameters, Hybrid (h) parameters, g-parameters, Scattering (S) parameters and their suitable applications (4L)

Idea of reciprocal and symmetric networks. Equivalent network parameters of series and parallel connections of networks (2L)

Analyses and synthesis of R-L-C networks [8 Lectures]:

Analyses of R-L, L-C, R-C circuits under DC and AC excitations. Finding out initial conditions and the solution of differential equations associated with RLC circuits in time domain (4L)

Network functions, Foster and Cauer synthesis, Helmholtz delay concept. (2L)

Series and parallel resonances, Q-factors, selectivity (2L)

Frequency domain analyses [8 Lectures]:

Idea of complex frequency and s-domain. Time domain to frequency domain transformation (4L)

Applications of Laplace and Fourier transforms in electric circuits. Poles and zeros of a network, Bode plot, stability analyses (4L)

Filter synthesis [6 Lectures]:

Filter definitions and specifications, basic L-C filter, lattice structure (2L)

m-derived filter, Butterworth and Chebyshev filters, active filter(4L)

N.B. *A total of six more class sessions will be included to solve numerical problems.*

Textbook

1.V. Valkenberg, (2007), "Network Analysis," Prentice Hall International Edition
2.D. Chattopadhyay and P.C. Rakshit, (2000), "Fundamentals of Electric Circuit Theory," S. Chand & Company
3.C.K. Alexander and M.N.O. Sadiku, (2003) "Fundamentals of Electric Circuits," McGraw Hill.
4.E. A. Guillemin, (1953) "Introductory Circuit Theory," John Wiley and Sons

Self Learning Material

1.MIT open course on "Circuits and Electronics," https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-002-circuits-and-electronics-spring-2007/.

Title	**Engineering Electromagnetics**	Number	**EEL2XXX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. 2nd Year	Type	Compulsory
Prerequisite	Electromagnetism and Optics		

Objectives

The Instructor will:

1. Familiarize behavior of Electromagnetic wave propagation in different medium and its application to solving practical electromagnetic fields problems
2. Provide basic understanding about transmission line and radiating systems for solving engineering electromagnetic problems
3. Provide basic understanding of wave propagation used in practical wireless propagation systems.

Learning Outcomes

The students are expected to have the ability to:

1. Formulate and analyse problems involving lossy media with planar boundaries using uniform plane waves.
2. Solve engineering problems involving transmission lines, metallic/dielectric waveguides.
3. Obtain basic understanding of different radiating systems and be able to use these in the design of rudimentary wireless communications systems

Contents

Review of Maxwell's equations [4 Lectures]: Review of Maxwell's Equation, time-harmonic fields, scalar and vector potentials, boundary conditions, Uniform plane wave

Plane waves at boundaries [5 Lectures]:Plane wave reflection and refraction at boundaries: Normal and oblique incidence, Brewster angle

Plane waves in dispersive media [5 Lectures]:quarter wave matching, wave propagation in dispersive media

Transmission Lines theory [5 Lectures]: Transmission line parameters and equations, Input impedance, standing wave ratio and power

Transmission Lines application [5 Lectures]: Smith chart, Impedance matching, Applications of transmission lines, Transient on transmission lines

Guided wave [5 Lectures]: TE, TM and TEM waves, parallel-plate waveguide

Waveguides [5 Lectures]: rectangular and cylindrical waveguides, waveguide resonators, dielectric guides

Antennas [8 Lectures]:

Hertzian dipole, half-wave dipole and quarter-wave monopole antennas, small loop antenna, antenna characteristics and arrays(5L)

Wave propagation: Ground wave propagation, ionospheric propagation (3L)

Textbook

1. Hayt, W. H. & Buck, J. A.,(2015), Engineering Electromagnetics, 6th Edition, Tata McGraw-Hill
2. Sadiku, M. N. O., (2015), Principles of Electromagnetics, 6th edition, Oxford University Press
3. David K. Cheng, (1989), Fields and Waves Electromagnetics, 2nd edition, Pearson Education

Self Learning Material

1. Kumar P., Electromagnetic Theory, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108/104/108104087/#

Preparatory Course Material

Electromagnetics and Applications, Department of Electrical engineering and Computer Science, Massachusetts Institute of Technology, MIT OpenCourseWare,https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-013-electromagnetics-and-applications-fall-2005/

Title	**Digital Design**	Number	**EELXXX0**
Department	Electrical Engineering	L-T-P [C]	2–0–2 [3]
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Introduction to Electrical Engineering		

Objectives

The Instructor will:

1. Provide the fundamental concepts in digital logic and system design.
2. Emphasize the modern design methodology to enable design practices using CAD tools.

Learning Outcomes

1. The students are expected to have the ability to Design and implement simple digital systems on FPGA boards.

Contents

Digital Logic Families, Voltage levels, Noise Margin, Power Dissipation, Fan-In, Fan-Out, CMOS Logic [3 lectures]
Introduction to HDL, Design flow, Number representation, Arithmetic circuits: Fast Adders, Multipliers. [5 lectures]
Gate delays, Transient output.[2 lectures]
Multiplexers, Encoders, Decoders, Code Converters [5 lectures]
Design and Analysis of Synchronous circuits, Memory Element in HDL, Counters and Shift Registers.[5 lectures]
State Diagram, State Table, State Assignment and Reduction, Design of Finite State Machines (Melay and Moore), Timing analysis [5 lectures]
Programmable Logic Devices: PLA, PAL, CPLD, FPGA. Implementation with FPGA. [3 lectures]

Lab Experiments on Designing Arithmetic circuits, Universal Shift Registers, Frequency Divide and Timing circuits, ALU, UART, Serial Peripheral Interface, VGA, Control Applications: Vending Machine, Traffic Light Controllers, Game Circuits, Motor Control.

Textbooks

1. Brown S. and Vranesic Z., (2013), Fundamentals of Digital Logic with Verilog Design, McGraw-Hill, 3rd Edition.
2. Unsalan C., Tar B., (2017), Digital System Design with FPGA: Implementation Using Verilog and VHDL, McGraw-Hill Education.
3. Mano M.M., Ciletti M.D., (2018), Digital Design: With an Introduction to the Verilog HDL, VHDL and System Verilog, Pearson.

Self Learning Material

1. Roychoudhury, D., Digital Systems Design, Department of Electrical Communication Engineering, Indian Institute of Technology Kharagpur https://nptel.ac.in/courses/117/105/117105080/

Title	**Analog Circuits**	Number	
Department	Electrical Engineering	L-T-P [C]	3–0–3 [4.5]
Offered for	B. Tech	Type	Compulsory
Prerequisite			

Objectives

The Instructor will:

1. Familiarize students with the concepts of analog circuits and give them a comprehensive overview of various amplifiers.
2. Deliver the knowledge of analog circuits by focusing on design and implementation.

Learning Outcomes

The students are expected to have the ability to:

1. Implement the concepts of CMOS Analog Design on real world problems and applications.
2. Design various analog circuits like single stage, differential amplifiers, operational amplifiers, filters for given specifications.

Contents

MOS Field-Effect Transistors: MOSFETs and its characteristics, operating modes [3 lectures]
single stage amplifier, small signal equivalent circuits [5 lectures]
Amplifier configurations [2 lectures]
Concept of biasing, cascode and cascade amplifiers, current mirrors [5 lectures]
Differential amplifiers: MOS differential pair, large and small signal analysis including common mode range and output swing, common mode rejection, passive and active loads [5 lectures]
Frequency response of amplifiers: Fundamental concepts, High frequency model of transistors
Frequency compensation, Miller's theorem [5 lectures]
Feedback: Negative feedback, Gain Desensitization, Bandwidth modification, Modification of I/O impedances, sense and Return techniques, Stability in feedback systems [5 lectures]
Output Stages and Power Amplifiers: Basic stages, large signal considerations, class A, class B and class AB configurations, low drop out regulators [5 lectures]
Operational Amplifiers: Op-Amp characteristics and specifications, concept of virtual ground [3 lectures]
Inverting and non-inverting amplifiers, op-amp applications including voltage summer, integrator, differentiator, instrumentation amplifiers [4 lectures]

Lab Experiments: It will include design and analysis of various analog circuits like single-stage amplifiers [3 labs], differential amplifiers [2 labs], operational amplifiers and frequency compensation [3 labs], output stages [2 labs] for given specifications and applications. Students will be introduced with different circuit and design parameters like gain, bandwidth, ICMR, CMRR, PSRR, slew rate and others through DC, AC and transient analysis using SPICE simulations. It will also include implementation & characterisation of discrete off-the-shelf components using breadboard.

Textbook

1. Sedra, A. S., Smith, K. C., and Chandorkar, A. N., (2013), Microelectronic Circuits: International Version, 6th Edition, Oxford University Press
2. Razavi, B., (2016), Design of Analog CMOS Integrated Circuits, 2nd Edition, McGraw-Hill Education.
3. Gray, P. R, Hurst, P. J., Lewis, S. H., and Meyer, R. G., (2020), Design of Analog Integrated Circuits: 5th Edition, Wiley

Self Learning Material

1. Nagendra Krishnapura, Analog Integrated Circuit Design, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/11710603

Title	**Electrical Machines**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Introduction to Electrical Engineering, Circuit Theory		

Objectives

The Instructor will:

Provide understanding of construction, principle of operation, performance, and control of various electrical machines used in the industry using power electronic converters

Learning Outcomes

The students are expected to have the ability to:

1. Analyze performance of different electrical machines
2. Understand and develop converters and their control methodologies required for various electrical machines used in industry

Contents

Transformers [7 Lectures]:

Three phase transformers- connections, testing, three winding transformers (5L)

Auto transformers, tap-changing transformers (2L)

Induction machines [12 Lectures]:

Production of rotating magnetic field in three phase and two-phase ac machines-torque development- Types of IM-Equivalent circuit-Slip-torque characteristics (5L)

Testing of 3-phase Induction motor -harmonic effects- Induction generator and its control (5L)

Principle of operation of single phase induction motor and its equivalent circuit (2L)

Synchronous machines [10 Lectures]:

Principle-mathematical model of cylindrical and salient pole machines based on armature reaction (4L)

Regulation, operation with infinite bus (4L)

Synchronous motor- control (2L)

DC motor control [4 Lectures]: AC-DC and DC-DC converter topologies and their applications in control of DC motors

Induction machine control [9 Lectures]:

DC-AC and AC-AC converter topologies (4L)

Their applications in constant torque, constant power and slip power control of induction machine (5L)

Textbook

1. Sen, P.C., (2007), *Principles of Electric Machines and Power Electronics*, 2nd Edition, Wiley
2. Fitzgerald, A.E., Kingsley, C. Jr., Umans, S.D., (2003), Electrical Machinery, 6th Edition, Tata McGraw-Hill
3. Dubey, G.K., (2001), Fundamentals of Electrical Drives, 2nd Edition, Alpha Science International Ltd

Self Learning Material

1. Bhuvaneswari, G., *Electrical Machines,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi
   https://nptel.ac.in/courses/108/102/108102146/
2. Das,S.D., *Fundamentals of Electric Drives,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur
   https://nptel.ac.in/courses/108/104/108104140/
3. Say, M.G., (1983), Alternating Current Machines, Pitman Publishing

Title	**Control Systems**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–3 [4.5]
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Signals and Systems		

Objectives

The Instructor will:

1. Introduce Linear Time Invariant System.
2. Teach design of linear feedback controller using time and frequency domain methods.

Learning Outcomes

The students are expected to have the ability to:

1. Analyze linear control system and to understand effect of feedback.
2. Design linear controllers.

Contents

Mathematical modeling of physical systems [8 Lectures]:

State variable and Transfer function representations; Examples of modeling different types (e. g. Electrical, mechanical, chemical, biological, social etc.) systems [3L]

Duality between the elements of different types of systems. Linearity and linearization, Transfer function and its interpretation in terms of impulse and frequency responses, Block-diagram and signal flow graph manipulations [5L]

Characterization of systems [7 Lectures]:

Time domain response for first order and second order systems; Damping ratio and natural frequency; Effect of dominant poles and zeros on system response; Concept of system Stability, Routh array, [4L]

Frequency domain response of LTI system; peaking frequency, bandwidth; Link between time and frequency domain response indices.[3L]

Analysis of Feedback [6 Lectures]:

Sensitivity and complementary sensitivity function, Disturbance and noise reduction, [3L]

Structured and unstructured plant uncertainties. Steady state errors and system types [3 Hours]

Analysis of closed loop systems[13 Lectures]:

Stabilityand relative stability [1L]

Root-locus approach [5 L]

Bode and Nyquist stability criterion [4L]

PID and Lag-Lead Controller Design[3 L]

State space modelling and state feedback control [8 Lectures]:

State space modelling, [2L]

Controllability and observability, [2L]

State feedback and observer design [4L]

Laboratory Classes (10-12 Classes)

A few experiments will be conducted on simulation of different systems i.e. temperature control, power converter control using MATLAB as a tool. Experiments on servo position control, inverted pendulum, helicopter emulator system, Active suspension, Magnetic Levitation, coupled tank system.

Textbooks

1. Franklin, G. F. , Powell, J. D., and Emami-Naeini, A. E.,(2002), Feedback Control of Dynamic Systems, Prentice Hall Inc.
2. Nise, N., (2007), Control Systems Engineering, Wiley India
3. Gopal, M., (2008), Control Systems; Tata McGraw Hill

Self Learning Material

1. Gopal, M., Control Engineering, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/108102043/

Title	**Communication Systems**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P[C]	3–0–0 [3]
Offered for	B. Tech. 3rd Year	Type	Compulsory
Prerequisite	Signals and Systems, Fundamentals of Probability		

Objectives

The Instructor will:

Provide students an understanding of the concepts related to transmission and reception techniques for communications

Learning Outcomes

The students are expected to have the ability to:

1. Analyze and design basic communications systems
1. Compare and contrast the strengths and weaknesses of various communication techniques

Contents

Introduction to Communication Systems [6 lectures]:
Basic building blocks and quality of service requirements of communication systems [2L],
Channel and noise modelling, power spectral density of noise, noise through LTI systems [4L].
Analog Modulation [4 lectures]:
Need for modulation, Amplitude Modulation (AM), frequency division multiplexing, spectrum of AM [2L],
Angle Modulation, spectrum of angle modulated signal [2L].
Pulse Modulation [5 lectures]:
The sampling theorem and time-division multiplexing [2L],
Pulse modulation techniques, generation and detection of pulse modulation [3L].
Digital Transmission at Baseband [12 lectures]:
Quantization, pulse code modulation, line codes, spectral characteristics of line codes [4L],
Matched filter receiver, inter-symbol interference, eye-patterns [4L],
Nyquist's criterion for ISI free transmission, equalization and OFDM [4L].
Digital Transmission at Passband [15 lectures]:
Binary digital modulation, QAM, signal constellation [4L],
spectral characteristics of digital modulated signals [2L],
digital receiver design - correlator receiver, optimal detectors [4L],
bit error rate performance analysis over AWGN channels, power and bandwidth efficiency [5L]

Textbook

1. Haykin, S. and Moher, M. (2009), *Communication Systems*, 5th Edition, Wiley Press
2. Lathi, B. P., Ding, Z., and Gupta, H. M. (2017), *Modern Digital and Analog Communication Systems*, 4th Edition, Oxford University Press
3. Madhow, U., (2008), *Fundamentals of Digital Communication*, 1st Edition, Cambridge University Press

Self Learning Material

1. Jagannatham, A., *Principles of Communication Systems I and II,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur
   https://nptel.ac.in/courses/108/104/108104091/ and https://nptel.ac.in/courses/108/104/108104098/

Title	**Communication Systems Lab**	Number	EEP3XX0
Department	Electrical Engineering	L-T-P [C]	0–0–3 [1.5]
Offered for	B. Tech.	Type	Compulsory
Prerequisite	Communication Systems		

Objectives

The instructor will:

1. Familiarize students with the generation and detection of analog modulated signals.
2. Expose students to end-to-end implementation of digital communication systems.

Learning Outcomes

The students are expected to have the ability to:

1. Design, implement and test modulator and demodulator for different types of communication schemes.
2. Implement end-to-end digital communication systems over wireless links.

Contents

1. An introduction to measurement equipment like Signal Analyzer, AFG, Oscilloscope.
2. Generation and detection of analog modulated signals.
3. Study and implementation of phase locked loop.
4. Generation and detection of pulse modulation schemes.
5. Implementation of ISI channels and equalization.
6. Generation and characterization of BPSK/QPSK modulated signals.
7. Study and implementation of end-to-end communication system with digital modulation. (3)
8. Demonstration of end-to-end optical communication systems (3)

Textbook

1. Haykin, S. and Moher, M. (2009), *Communication Systems*, 5th Edition, Wiley Press

Reference Books

1. Lathi, B. P., Ding, Z., and Gupta, H. M. (2017), *Modern Digital and Analog Communication Systems*, 4th Edition, Oxford University Press

Title	**Power Engineering**	Number	**EE3XXX**
Department	Electrical Engineering	L-T-P [C]	3–0–3 [4.5]
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Electrical Machines, Engineering Electromagnetics		

Objectives

The Instructor will:

1. Provide an understanding of the functionalities of various components of the modern power system and their modelling
2. Give exposure to modern power electronic converters to enhance the efficiency, economy, and controllability of the existing power system

Learning Outcomes

The students are expected to have the ability to:

1. Model and evaluate the performance of a power system
2. Propose converter topologies and their control strategies for enhancing the power system performance

Contents

Introduction [2 Lectures]: Structure of the conventional and modern power systems, conventional and renewable energy sources, load curve

Mechanical aspects of overhead transmission line [4 Lectures]: The catenary curve, sag, and tension

Modeling and performance of transmission lines [10 Lectures]:

Conductor types, inductance and capacitance calculations (5L)

Various models of transmission line representation (2L)

Voltage regulation and efficiency, power circle diagram, need for compensation to enhance the performance (3L)

Representation and modeling of the power system [5 Lectures]: Single line diagram, substation layout, mathematical models of various components, impedance diagram, per-unit system, per-unit reactance diagram

Underground cables [6 Lectures]:

Construction, grading of cables, dielectric loss and charging effect (4L)

Merits of underground cables, need of dc transmission (2L)

Corona [4 Lectures]: Corona phenomena, critical disruptive voltage, corona loss, factors affecting corona loss

Series and shunt compensation in transmission and distribution [5 Lectures]: Principle of series and shunt compensation, introduction to series and shunt compensation devices

Integration of renewable energy sources [6 Lectures]:

Principles of solar PV and wind energy conversion- concept of MPPT in SPV and WE (4L)

Converter topologies for grid integration techniques for solar PV and WE (2L)

Laboratory Experiments

Substation layout; estimation of transmission line parameters; performance of transmission lines with various models; reactive power compensation in transmission; power factor correction; testing of cables; implementation of series compensation; implementation of shunt compensation

Textbook

1. Stevenson,W.D.Jr., (1982), Elements of Power System Analysis, McGraw Hill International
2. Wadhwa,C.L., (2010), Electrical Power Systems, New Age International Publishers
3. Bollean,M.H.J., Hasan,F., (2011), Integration of Distributed Generation in the Power Systems, Wiley India Press

Self Learning Material

1. Sinha,A.K., *Power System Analysis,* NPTEL Course Material, Department of Electrical Engineering, IIT Kharagpur, https://nptel.ac.in/courses/108/105/108105067/
2. Das, D., *Power System Analysis,* NPTEL Course Material, Department of Electrical Engineering, IIT Kharagpur, https://nptel.ac.in/courses/117105140/

Title	**Digital Signal Processing**	Number	EEL3XXX
Department	Electrical Engineering	L-T-P [C]	2–0–0 [3]
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Signal and Systems		

Objectives

The Instructor will:

Provide students an understanding of analysis and synthesis of algorithms and systems that process discrete time signals, with emphasis on realization and implementation

Learning Outcomes

The students are expected to have the ability to:

1. interpret and process discrete/digital signal and systems
2. analyze and provide solutions to practical implementation issues of DSP systems

Contents

Review of Discrete Time signals: Sequences, Discrete time processing of continuous time signals, Practical Sampling and reconstruction, sampling of band-pass signals; Discrete systems: attributes, DTFT, z-transform, Inverse systems (3 lectures)

Computation of the Discrete Fourier transform (9 lectures):

The discrete Fourier transform (DFT), Sampling of the discrete time Fourier transform, properties of the DFT, linear convolution using the DFT (5 lectures)

Fourier analysis of the signals using the DFT, Direct computation of the DFT, Decimation-in-time FFT algorithms, Decimation-in-frequency FFT algorithm (4 lectures)

Design of FIR filters (8 lectures):

FIR filters with linear phase (2 lectures)

Design of FIR filters by windowing (2 lectures)

Park-McClellan's method, Direct and Cascade form structures for FIR filters (4 lectures)

Design of IIR filters (14 lectures):

Introduction to IIR filter design, Design of continuous time low pass filters (3 lectures)

Transformation of continuous time filters to discrete time filters (3 lectures)

Design examples for low pass IIR filters, Frequency transformations of low pass filters. (5 lectures)

Cascade, Parallel, Cascade-Parallel and Lattice structures for IIR filters (3 lectures)

Multirate signal processing (5 lectures):

Sampling rate conversion, implementation of Multirate systems, filter design for Multirate systems (2 lectures)

Noble identities, Type I & II polyphase representation, concept of Perfect Reconstruction Filter Banks (PRFB) (3 lectures)

Finite wordlength effects: Number representation, quantization of filter coefficients, Effects of finite wordlength on digital filters. (3 lectures)

Reference Books

1. Proakis, J. G. and Manolakis, D.G. (2007) *Digital Signal Processing*, 4th Edition Prentice Hall
2. Mitra, S. K., (2008) *Digital Signal Processing*, 3nd Edition, McGraw Hill
3. Manolakis, D.G., and Ingle, V. (2011) *Applied Digital Signal Processing*, 1st Edition, Cambridge University Press

Self Learning Material

1. Basu, T. K., Digital Signal Processing, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/108105055/
2. Dutta Roy, S. C., Digital Signal Processing, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/117/102/117102060/

Preparatory Course Material

Jagannatham, A. K., *Principles of Signals and Systems*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104100/

Title	**Data Communication Networks**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech.	Type	Compulsory
Prerequisite	Communication Systems		

Objectives

The Instructor will:

1. Provide background to understand the network protocols and architectures

Learning Outcomes

The students are expected to have the ability to:

1. Model data networks and analyze their performance
2. Understand the issues and design the next-generation data networks

Contents

Introduction [2 lectures]: Introduction to data communication, layered architecture.

Data Link Control [8 lectures]:

Measure of information, entropy, source coding [3L],

Error detection: linear block code examples, cyclic redundancy check [3L],

Retransmission strategies: ARQ protocols, framing [2L].

Delay models in Data Networks [8 lectures]:

Introduction to Queueing theory, Little's theorem, different queueing systems [4L],

Priority queueing, Burke's theorem, network of queues [4L].

Multi-access Communication [10 lectures]:

Random access techniques, tree algorithms [4L]

FDMA, TDMA, CDMA [4L]

Reservation, polling, token ring and buses, High speed LANs [2L]

Circuit Switching and packet switching [3 lectures]: Circuit-switched networks, packet switching principles, introduction to switch architecture, high speed switch scheduling

Routing in Data Networks [6 lectures]:

Spanning trees, shortest path routing [3L]

Broadcast routing, optimal routing [3L]

Flow and congestion control [2 lectures]: Window/Credit Schemes, Rate based schemes.

TCP/IP and ATM [3 lectures]: TCP operation, TCP error, flow and congestion control, ATM reference architecture, transmission of ATM cells, ATM adaptation layer, traffic and congestion control.

Textbook

1. Bertsekas, D. P. and Gallager, R. G., (1992), Data Networks, 2nd Edition, Prentice Hall
2. Stallings, W., (2007), *Data and Computer Communications*, 8th Edition, Pearson
3. Forouzan, B. A., (2007), *Data Communication and Networking*, 4th Edition, McGraw Hill

Reference Book

1. Tanenbaum, A.S. and Wetheral, D.J. (2011), Computer Networks, 5th Edition, Pearson

Self Learning Material

1. Modiano, E., *Data Communication Networks,* MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-263j-data-communication-networks-fall-2002/index.htm
2. Pal, A., Data Communication, NPTEL Course Material, Department of Computer Science and Engineering, Indian Institute of Technology Kharagpur,https://nptel.ac.in/courses/106105082/

Title	**Embedded Systems**	Number	**EEL3XX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Core
Prerequisite	Basics of Computer Architecture		

Objectives

The Instructor will:

1. Introduce concepts of different architectures and programming languages of embedded processors.
2. Introduce concepts of Real time system and design of embedded systems.

Learning Outcomes

The students are expected to have the ability to:

1. Program and to design embedded system using embedded processors based on system specifications.
2. Use different IDE and debugging tools.

Contents

Architecture of ARM Cortex M3 and Cortex A series processors; [5L]
Introduction to Embedded Multicore Architecture; Multicore Processor Design Technique; Interconnection networks for Multicore Processors; [5L]
Programmable Systems on Chip; Architecture of DSPs; Fixed and Floating point devices; Security at Hardware level [5L]
Selection of DSP chips; Performance assessment of embedded processor [2L]
Programming of Embedded processors using assembly and C; [5L]
Models for program --data flow graphs; Programming of multicore processors; Assembly language programming of ARM Cortex M3;[4L]
Hardware software co-design; [2L]
Processes and real time operating systems; Multi-rate system;[2L]
Real time scheduling algorithms e.g. RMA, EDF and their variants; [4 L]
Energy efficient scheduling algorithms; Structure of Real Time operating system; Overhead of RTOS; [4L]
Example of Real time operating systems e.g. real time Linux, Keil RTX Real-Time Operating System, programming of embedded processors with RTOS [4L]

Text Books

1. Wolf, M., (2014), High Performance embedded Computing: Applications in Cyber Physical Systems and Mobile Computing, Elsevier
2. JosephYiu, (2013), The definitive Guide to ARM Cortex M3 and M4 Processors, Elsevier.
3. Buttazzo, G., (2011), "Hard Real-Time Computing Systems: Predictable Scheduling Algorithms and applications, Springer

Self Learning Material

1. Chaudhury,S., *Introduction to Embedded Computing* , NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/108102045/#

PreparatoryCourse Material

1. Wolf, M., "Computers as Components: Principles of Embedded Computing System Design" Third Edition, Elsevier 2012.

Title	**Digital Systems Lab**	Number	**EEP3XX**
Department	Electrical Engineering	L-T-P [C]	0–0–3
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Computer Architecture		

Objectives

The Instructor will:

1. Provide knowledge of hardware/software tools and interfacing of embedded processor
2. Provide knowledge of programming of embedded Processor

Learning Outcomes

The students are expected to have the ability to:

1. Use IDEs for writing software for embedded processors.
2. Design and test embedded systems for different application.

Contents

Experiments on Configuration of RTOS, booting sequence; evaluating scheduler responsiveness; using different peripherals like GPIO, Timers, I^2C bus etc. Operating System for IoT devices; Platform for heterogenousIoT devices; Experiments on simulators of Computer Architecture.

Textbook

1. Xiao, P., (2018), Designing Embedded Systems and the Internet of Things (IoT) with the ARM®Mbed™, John Wiley & Sons Ltd
2. Norris, D., (2018) Programming with STM32: Getting Started with the Nucleo Board and C/C++, McGraw Hill

Title	**Electrical Machines Lab**	Number	**EEP3XX0**
Department	Electrical Engineering	L-T-P [C]	0–0–3 [1.5]
Offered for	B.Tech.	Type	Compulsory
Prerequisite	Electrical Machines		

Objectives

The Instructor will:

Provide practical exposure on operation, testing and performance evaluation of various electrical machines

Learning Outcomes

The students are expected to have the ability to:

1. Test, determine the parameters and evaluate the performance of various electrical machines

Contents

Laboratory Experiments

Experiments related to the following topics will be conducted:

Testing of transformers, parallel operation of transformers, load test of transformers, separation of losses, three phase connections, converter based three phase induction motor speed control, performance predetermination of induction motor, load test of induction motor, regulation of alternator, performance of alternator connected to infinite bus, slip test, parallel operation of induction generator with ac grid, speed control of DC motor using converters

Textbook

1. Say,M.G., (1983), *Alternating Current Machines*, Pitman Publishing
2. Fitzgerald,A.E., Kingsley,C.Jr., Umans,S.D., (2003), *Electrical Machinery*, 6th Edition, Tata McGraw-Hill
3. Dubey,G.K., (2001), *Fundamentals of Electrical Drives*, 2nd Edition, Alpha Science International Ltd

15. Detailed Course Content of Programme Elective Courses

Communications

Title	**Information Theory and Coding**	Number	**EEL3XX0**
Department	EE	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech.	Type	Elective
Prerequisite	Communication Systems, Basics of Probability		

Objectives

The Instructor will describe mathematical principles of communication that govern the compression and transmission of data and the design of efficient methods of doing so

Learning Outcomes

The students are expected to have the ability to:

1. Formulate the fundamental concepts of information theory such as entropy, mutual information, channel capacity
2. Elaborate the principles of source coding and data transmission
3. Apply information theoretic methods to communication systems

Contents

Mathematical definition of information and the study of its properties [8 Lectures]:
Measure of information, entropy, entropy rate, relative entropy, differential entropy (4 Lectures)
Jensen's inequality, data processing inequality, Fano's inequality (4 Lectures)
Source coding [4 Lectures]: Efficient representation of message sources- AEP, Shannon-Fano-Elias, arithmetic coding.
Communication channels and their capacity [7 Lectures]:
Mutual information, information channel capacity (3 Lectures)
Channel coding theorem (4 Lectures)
Coding for reliable communication over noisy (Gaussian) channels. (5 Lectures)
Gaussian multi-user communications [8 Lectures]:
Parallel Gaussian channels (2 Lectures)
Multiple access channels (3 Lectures)
Broadcast channels (3 Lectures)
Lossy source coding: approximate representation of message sources. (5 Lectures)
Information Theory and statistics (5 Lectures)

Textbook

Cover, T. M., and Thomas, J. A. , (2006), Elements of Information Theory, Wiley

Reference Book

1. Abramson, N., (1963), Information Theory and Coding, 1st Ed., McGraw-Hill Book Company Inc.
2. C. E. Shannon, (1948), A Mathematical Theory of Communications, Bell System Technical Journal

Self Learning Material

Merchant, S. N., *Information Theory and Coding,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Bombay, http://nptel.ac.in/courses/117101053/

Title	**Spread Spectrum Communications**	Number	**EEL4XX0**
Department	EE	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech.	Type	Elective
Prerequisite	Communication Systems		

Objectives

The Instructor will:

Present an analysis of the performance and design of spread-spectrum communication systems

Learning Outcomes

The students are expected to have the ability to:

1. Perform analysis on the performance of spread spectrum modulation formats.
2. Analyze the performance of spread spectrum systems in the presence of interference.
3. Analyze the performance of spreading code acquisition and tracking systems.

Contents

Types of spread spectrum systems [7 Lectures]: direct sequence (2 Lectures), frequency hopping (2 Lectures), time hopping (2 Lectures), chirp and hybrid methods, OFDM-SS (3 Lectures)
Sequences for spread spectrum communication: features, properties and generation methods (5 lectures)
Initial code acquisition: techniques and performance analysis (5 lectures)
Code tracking: techniques and performance analysis (5 lectures)
Analytical Performance of spread spectrum systems (5 lectures)
Spread spectrum systems in jamming environments (5 lectures)
Low probability of intercept methods (5 lectures)
Spread spectrum and electronic counter measure (5 lectures)

Textbook

1. Dixon, R. C., (2010), Spread spectrum Systems, Wiley
2. Simon, M. K., Omura, J. K., Scholtz, R. A. and Levitt, B. K., (2002), Spread Spectrum Communications Handbook, McGraw Hill
3. Torrieri, D., (2015), Principles of Spread Spectrum Communication Systems, Springer

Self Learning Material

Sen, D., *Spread Spectrum Communications and Jamming,* NPTEL Course Material, Department of Electronic and Communication Engineering, Indian Institute of Technology Kharagpur, http://nptel.ac.in/courses/117105136/

Title	**Optical Communication Systems**	Number	**EEL4XX0**
Department	Electrical Engineering	L-T-P[C]	3–0–0 [3]
Offered for	B. Tech.	Type	Elective
Prerequisite	Communication Systems, Engineering Electromagnetics		

Objectives

The Instructor will:

Provide students an understanding of the concepts related to transmission and reception techniques for optical communication systems

Learning Outcomes

The students are expected to have the ability to:

1. Analyze and design basic optical communications systems
2. Compare and contrast the features of various optical communication techniques

Contents

*Introduction to Optical Communication Systems [*2 lectures*]:*

Basic building blocks, optical transmitters, optical receivers, optical amplifiers [2L].

Optical transmission system considerations [8 lectures]:

Attenuation, dispersion, line coding schemes, eye pattern [4L]

Noise effects, attenuation and dispersion limited link design, pulse on pedestal power penalty [4L]

Modulation and Detection Techniques [12 lectures]:

Optical modulation techniques, Intensity Modulation/Direct Detection system, SIM [4L]

Coherent Optical Systems, homodyne and heterodyne detection [3L]

BER performance in coherent and non-coherent modulation schemes [5L]

Optical modulators [8 lectures]:

Electro-Optic and Acousto Optic [4L]

Tunable optical filters (grating filters, micro-ring resonators) [4L]

Channel Impairments [12 lectures]:

Optical fiber considerations-Pulse broadening [2L]

Free space effects-turbulence models, weather conditions viz. fog, haze, drizzle [3L] under-water impairments [2L]

Performance analysis: BER analysis under channel impairments, link budget, channel capacity [5L]

Textbook

1. Keiser, G. (2017), Optical Fiber Communications, 5 th Edition, McGraw Hill
2. Chadha, D. (2013), Terrestrial Wireless Optical Communications, 1 st Edition, McGraw Hill.
3. Chen A. and Murphy, E. (2011), Broadband Optical Modulators: Science, Technology and Applications, 1 st Edition, CRC Press.

Self Learning Material

Kumar, K. P., *Fiber-Optic Communication Systems and Techniques,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur,
https://nptel.ac.in/courses/108/104/108104113/

Title	**Satellite Communications**	Number	EEL4XX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech.	Type	Elective
Prerequisite	Communication Systems, Data Communication Networks		

Objectives

The Instructor will:

Provide an overall understanding of satellite communication systems, technologies and techniques and will equip them with the design tools for communication payload design.

Learning Outcomes

The students are expected to have the ability to:

1. Explain the structure, techniques and technology for satellite communication systems.
2. Design and plan satellite communication links for a prescribed quality of service.

Contents

Introduction of satellite systems [11 Lectures]:

Services, frequency planning, space segment components, earth stations (5L)

Bus and payloads, antennas and coverage (3L)

Transparent and non-transparent transponders (3L)

Satellite Systems Planning [16 Lectures]:

Free space loss, EIRP, noise sources, noise temperature, sky noise G/T ratio (5L)

C/N calculation for uplink and downlink (2L)

Modulation, Demodulation and BER Analysis for APSK, OQPSK, CPFSK (5L)

Intermodulation, back-off, interference and C/I calculation (4L)

Multiple Access in Satellite systems [7 Lectures]:

Fixed and demand assignment, traffic matrices mapping (3L)

FDMA & TDMA operation, MF TDMA operation (4L)

Satellite system Future Trends [8 Lectures]:

Standards issues and technology developments: BSM, DVB-S2, Satellite UMTS (5L)

A state-of-the art update on current innovations and new systems proposals: Hybrid Satellite-Terrestrial Communications (3L)

Textbook

1. Maral, G., Sun, Z., and Bousquet, M., (2009), Satellite Communications Systems: Systems, Techniques and Technology, Wiley & Sons
2. Roddy, D., (2017), Satellite Communications, McGraw Hill Education
3. Pratt, T., Bostian, C. W., and Allnutt, J., (2003), Satellite Communications, John Wiley & Sons

Self Learning Material

1. Bandyopadhyay, K., *Satellite Communication Systems,* NPTEL Course Material, Department of Electronic and Communication Engineering, Indian Institute of Technology Kharagpur, http://nptel.ac.in/courses/117105131/

Title	**Cellular Communication Networks**	Number	**EEL4XX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech.	Type	Elective
Prerequisite	Communication Systems, Data Communication Networks		

Objectives

The Instructor will:

1. Provide an understanding of fundamental issues related to frequency planning, resource allocation and interference management techniques in cellular communication networks.
2. Introduce concepts and techniques used in existing and emerging cellular communication systems.

Learning Outcomes

The students are expected to have the ability to:

1. Analyze and design operational cellular communications networks.
2. Compare and contrast the strengths and weaknesses of various cellular communication networks.

Contents

Introduction of cellular systems[9 Lectures]:
Channel models and impairments (5L)
Quality of service requirements, coverage planning (4L)
Interference management techniques[12 Lectures]:
Interference avoidance and interference cancellation(5L)
Interference alignment (4L)
Interference coordination – network MIMO (3L)
User and Resource Management [9 Lectures]:
Association and handover management (4L)
Transmit power control (5L)
Emerging Cellular Network Technologies[12 Lectures]:
Long Term Evolution (4L)
Long Term Evolution Advanced (3L)
5G technologies and beyond(5L)

Textbook

1. Miao, G., Zander, J., Sung, K., & Ben Slimane, S., (2016), Fundamentals of Mobile Data Networks, Cambridge University Press
2. Rappaport, T. S., (2010), Wireless Communications – Principles and Practice, Pearson
3. Bolcskei, H., Gesbert, D., Papadis, C. B., and Veen, A. V., (2006), Space-time Wireless Systems, Cambridge Press.

Self Learning Material

1. Koilpillai, D., *Introduction to Wireless and Cellular Communications,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/106/106/106106167/
2. ETSI 5G Technologies https://www.etsi.org/technologies/5g

Title	**Microwave engineering**	Number	**EEL4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech	Type	Elective
Prerequisite	Engineering Electromagnetics		

Objectives

The Instructor will:

1. Provide theoretical background to analyze microwave circuits and systems
2. Provide design principle of several commonly used microwave devices and sources

Learning Outcomes

The students are expected to have the ability to:

1. Have basic understanding of different techniques related to microwave circuits and systems
2. Design basic microwave components and antennas

Contents

Transmission lines: Review of wave equation and transmission line [5 Lectures]: stripline, micro-stripline; slotline; coplanar waveguide line; Wave propagation in planar lines: design, effective dielectric constant, attenuation, dispersion, power-handling capability

Impedance matching [3 Lectures]: Design of distributed circuits using planar lines, single and double stub matching, LC and multisection impedance matching network

Network analysis [5 Lectures]: scattering-matrix, representation, properties, shift in reference planes, generalized S-matrix; Signal flow graph; basics of network analyzer

Passive components [5 Lectures]: power splitters/combiners, directional couplers, Operation and S-matrices of resonators/cavities

Non-reciprocal components[3 Lectures]: isolators and circulators

Microwave filters [5 Lectures]: image parameter method; insertion loss method low pass filter prototype of Butterworth & Chebyshev response; filter transformation - impedance and frequency scaling, filter implementation - Richards transformation, Kuroda identities

Microwave Antennas [5 Lectures]: Planar dipole and monopole antenna, *folded dipole,* Microstrip antenna, introduction to slot antenna

Microwave broadband Antennas [3 Lectures]: Yagi-uda antenna, log-periodic antenna, helical antenna, biconical antenna, introduction to reflector antenna

Microwave solid state devices [4 Lectures]: RF diodes and transistors, IMPATT, Schottky, PIN diodes, HEMT Device

Microwave sources [4 Lectures]: Gunn Diode, klystron, magnetron

Textbook

1. D. M. Pozar, (2011), "Microwave Engineering," 4th ed. New York, NY, USA, Wiley
2. David K. Cheng, (1989), Fields and Waves Electromagnetics, 2nd edition, Pearson Education
3. Balanis C. A., (2016), Antenna Theory, Analysis and Design, 4th edition, Wiley Press

Self Learning Material

1. Kumar, G., *Microwave Theory and Techniques*, Department of Electrical Engineering, Indian Institute of Technology Bombay, https://nptel.ac.in/courses/108101112/
2. Vedio Lecture: Antenna Engineering, Dr. Anthony Ferraro, Penn State Univ., USA,http://www.engr.psu.edu/cde/courses/ee438/index.htm

Preparatory Course Material

1. Electromagnetics and Applications, Department of Electrical engineering and Computer Science, Massachusetts Institute of Technology, MIT OpenCourseWare, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-013-electromagnetics-and-applications-fall-2005/

Signal Processing

Title	**Signal Compression**	Number	EE4XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Program Elective
Prerequisite	Signal and Systems, Probability and Statistics		

Objectives

The Instructor will:

Provide background in fundamental signal compression techniques such as lossless and lossy techniques for different types of signals.

Learning Outcomes

The students are expected to have the ability to:

1. compress various type of signals such as audio and image
2. analyze the trade-off between compression, computational or implementational demand and quality of reconstructed signal.

Contents

Introduction to Signal Compression [5 Lectures]: Information and Entropy, Distortion Measures such as PSNR, mutual-information, divergence, and Kullback-Liebler number

Lossless and Lossy Coding [9 Lectures]: Huffman Coding, Arithmetic Coding, adaptive and predictive lossless coding (5 Lectures)

Subband Coding, QMF bank. (4 Lectures)

Quantization [7 Lectures]: Uniform and non-uniform Quantization, Vector Quantization, Structured Vector Quantization, Product Vector Quantization (4 Lectures)

Differential Coding, Delta Modulation. (3 Lectures)

Transform Coding [7 Lectures]:

Wavelets, Multi Resolution Analysis (4 Lectures)

Compression using DCT, DWT, KLT (3 Lectures)

Representation Based Techniques [6 Lectures]: Sparse Representation, Dictionary Learning Based Approaches (4 Lectures)

Machine Learning based Compression (2 Lectures)

Compression Standards [8 Lectures]:

JPEG, JPEG 2000 (4 Lectures)

H264, MPEG. (4 Lectures)

Textbook

1. Sayood, Khalid, (2017). Introduction to data compression. Morgan Kaufmann.
2. Gersho, Allen, and Robert M. Gray, (2012). *Vector quantization and signal compression*. Vol. 159. Springer Science & Business Media.
3. Salomon, David, and Giovanni Motta (2010). Handbook of data compression. Springer Science & Business Media.

Self Learning Material

Prof. Ajit Rajwade, Digital Image Processing, Department of Electrical Engineering, Indian Institute of Technology Bombay, https://www.cse.iitb.ac.in/~ajitvr/CS663_Fall2018/

Preparatory Course Material:

Prof. S.C. Dutta Roy, Digital Signal Processing, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/117/102/117102060/

Title	**Speech Processing**	Number	EEL4xxx
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech.	Type	Program Elective
Prerequisite	Signal and Systems, Probability and Stochastic Processes		

Objectives

The Instructor will:

1. introduce the theory of signal processing applications on speech, to give information about human speech production and perception, voice production mechanism, and human perception systems.
2. provide an understanding of time frequency analysis of speech, Linear Prediction, speech analysis/synthesis.

Learning Outcomes

The students are expected to have the ability to:

1. analyze digital signals, e.g., audio signals, in the time, frequency and joint time-frequency domains
2. implement widely-used algorithms for speech analysis and speech processing in the frequency or time domain.

Contents

Introduction [6 Lectures]: Review of DSP basics, Filters, DFT, Short-time Fourier Transform, Spectrograms, Speech Production, Articulatory and Acoustic Phonetics
Time Domain Analysis [16 Lectures]:
Introduction to time series, probability models for time series, stationarity (5 Lectures)
Moving average (MA), Autoregressive (AR), ARMA and ARIMA models, Estimating the autocorrelation function and fitting ARIMA models. (6 Lectures)
Linear Prediction, Perceptually Based Linear Predictive Analysis, DPCM (5 Lectures)
Cepstral Analysis [6 Lectures]: Time and frequency domain features, Cepstral Analysis, Mel Cepstral Analysis, MFCC, Wavelets.
Hearing Perception [4 Lectures]
Applications [10 Lectures]:
Compression, Recognition, Noise Suppression (5 Lectures)
Music Event Classification, speech generation. (5 Lectures)

Textbook

1. Rabiner, L. and Schafer, R., (2011), Theory and Applications of Speech Processing, Pearson.
2. Rabiner, L. and Schafer, R., (2007), Introduction to Digital speech Processing, Publishers Inc.
3. Gold, B., and Morgan, N., (2011), Speech and Audio Signal Processing, John Wiley.

Self Learning Material

Prof. Alan W Black, Speech Processing, Carnegie Mellon University, http://www.speech.cs.cmu.edu/15-492/

Preparatory Course Material

Prof. S.C. Dutta Roy, Digital Signal Processing, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/117/102/117102060/

Title	**System Identification**	Number	EE4XXX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Program Elective
Prerequisite	Signals and Systems, Basics of Probability		

Objectives

The Instructor will provide students an understanding of system identification techniques and its applications.

Learning Outcomes

The students are expected to have the ability to apply the learned techniques to solve practical problems such as echo cancellation, active noise cancellation, and deconvolution.

Contents

Introduction to System Identification [5 Lectures]: What is System Identification? How can we derive Algorithms? How do we evaluate the Algorithms? Stochastic vs. Non-stochastic Formulation.
Nonparametric Identification [5 Lectures]: Impulse and Step Response, Correlation Methods, Spectral Analysis
Parameter Estimation [12 Lectures]:
Minimizing Prediction Error, Identifiability, Consistency, Biase (4 Lectures)
Least Squares Relations between Minimizing the Prediction Error and the MLE, MAP
(4 Lectures)
Convergence and Consistency, Asymptotic Distribution of Parameter Estimates, The Instrumental-Variable Method (4 Lectures)
Algorithms [8 Lectures]:
Computing the Estimates, Recursive Estimation (5 Lectures)
Kalman Filter Interpretation (3 Lectures)
Identification in Practice [7 Lectures]:
Aliasing due to Sampling, Closed Loop Data, Model Order Estimation (3 Lectures)
Bounded but Unknown Disturbances, Identification in the Worst Case, Optimal Algorithms, Optimal Inputs, Robustness Consideration (4 Lectures)

Applications [5 Lectures]: Echo Cancellation, Active Noise Cancellation, Deconvolution, Dehazing.

Reference Books

1. Ljung, Lennart (1998). System Identification: A Theory for the User. 2nd ed. Upper Saddle River, NJ: Prentice Hall.
2. Keesman, K. J. (2011). System identification: an introduction. Springer Science & Business Media.

Self Learning Material

Prof. Arun K.Tangirala , System Identification, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/103/106/103106149/

Preparatory Course Material

Prof. V.M. Gadre, Signals and Systems, NPTEL Course Material, Department of Electronics and Communication Engineering, Indian Institute of Technology Bombay, https://nptel.ac.in/courses/117/101/117101055/

Control Engineering

Title	**Modern Control**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0[3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Control Systems		

Objectives
The Instructor will:
1. Introduce time domain modeling of SISO and MIMO systems.
2. Teach design of feedback controller using different time domain techniques.

Learning Outcomes
The students are expected to have the ability to:
1. To analyze linear control system and to understand effect of feedback.
2. To design controllers and Observers using different techniques for SISO and MIMO systems.

Contents:
Review of state space modeling technique, Solution of state space equation, State transition matrix; Linearization of nonlinear equations [4 Lectures]

Discrete time system and difference equation representation of discrete time systems; solution of difference equation [4 Lectures]

Vector spaces and Linear operators [6 Lectures]: Definition of linear operators; Operator Norms; Adjoint Operator; rotational operators

Functions of Vectors and Metrices [6 Lectures]: Linear and multilinear functionals; quadratic forms; Bilinear forms as inner products; functions of matrices; Cayley Hamilton Theorem

*System Stability [5 Lectures]:*Lypunov Stability; classification of Equilibria; Lypunov's direct method; Relationship between different stability

Controllability and Observability [4 Lectures]: PBH test for controllability; decomposing system into controllable and uncontrollable subspaces;

Modal Controllability and Observability; Controllability and reahbility for discrete time systems; Observability and reconstructability [5 Lectures]

State feedback and observer design [8 Lectures]:
State feedback controller for SISO system; Multivariable canonical forms and state feedback controller design (4L)
Reduced order and full order observer design (4L)

Textbooks
1. John Bay (2008), Fundamentals of Linear State Space Systems; McGraw Hill.
2. Slotine, Jean-Jacques, and Weiping Li, (1991) Applied Nonlinear Control, Prentice-Hall.
3. Brogan, William L(1991), Modern Control Theory, 3/e, Prentice-Hall, I991.

Title	**Nonlinear and Adaptive Control**	Number	**EEL4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0[3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Control Systems		

Objectives

The Instructor will:

1. Introduce nonlinear and adaptive control systems.
2. Teach design and analysis of feedback controllers for nonlinear systems in the presence of uncertainties.

Learning Outcomes

The students are expected to have the ability to:

1. To analyze Nonlinear control systems.
2. To design controllers and Observers in the presence of uncertainty.

Contents:

Introduction to Nonlinear Systems:

Nonlinear models and nonlinear phenomena, Examples of nonlinear systems, [3 L]
Concept of equilibrium points, Limit cycles [3 L]
Small gain theorem, sector-based nonlinearities, Circle/Popov criteria [2 L]

Stability Results:

Lyapunov stability results, Barbalat's lemma, Krasovskii-LaSalle principle, Passivity theorems [7 L]
Feedback linearization. [3 L]

Reinforcement learning based control:

Basics of Reinforcement learning technique, policy iteration, value iteration [3 L]
Adaptive dynamic programming, Persistent Excitation. [4 L]
Neural network, online adaptive dynamic programming, online policy and value iteration, actor-critic method. [5 lectures]

Model predictive Control (MPC):

Understanding MPC problem and advantages, Control and prediction horizon, Controller design [5 L]
Application of Adaptive Controller. [4 L]

Textbooks

1. Hassan K Khalil, (2002) Nonlinear systems, Prentice hall
2. Kumpati S Narendra, Anuradha M Annaswamy, (2012), Stable adaptive systems, Courier Corporation
3. Francesco Borrelli, Alberto Bemporad, Manfred Morari, (2017), Predictive control for linear and hybrid systems, Cambridge University Press

Research Paper

1. Frank L Lewis and DragunaVrabie, Reinforcement learning and adaptive dynamic programming for feedback control, IEEE circuits and systems magazine, 2009.

Title	**Robust and Optimal Control**	Number	**EEL4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0[3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Control Systems		

Objectives

The Instructor will introduce various optimal and robust control techniques for feedback control systems.

Learning Outcomes

The students are expected to have the ability to:

1. To design and analyze feedback control systems in the presence of uncertainties.
2. To design optimal controllers for linear and nonlinear systems.

Contents

Preliminaries

Vector spaces and Linear operators, Review of state space modeling technique, Solution of state space equation, Euler-Lagrange equation [3 Lectures]

Controllability and Observability, State feedback controller, Observer. [5 Lectures]

Stability Results

Optimal Control Theory: Lyapunov stability, Routh-Hurwitz criterion, Nyquist criterion, Stabilizability and Detectability, [5 Lectures]

Optimal Control Theory

Principle of Optimality, Hamiltonian-Jacobi-Bellman (HJB) equation, LQR, Kalman filter, Relation between LQR and Kalman filter. [5 Lectures]

Robust control for Linear and Nonlinear Systems

Uncertainty classifications, Matched and mismatched uncertainties, Uncertainty in input matrix [4 Lectures]

Optimal control approach for robust controller design, Stability analysis of uncertain systems. [5 Lectures]

Kharitonov approach, H2 and H∞ Control: Function space, Computation of H2 and H∞ norm [5 Lectures]

Kharitonov theorem, Robust Control problem formulations and design. [5 Lectures]

***Applications**: Robust Active damping, Robust control of Robot Manipulator, Aircraft Hovering. [5 Lectures]*

Textbooks

1. K. Zhou, J. C. Doyle and K. Glover, (1995), Robust and Optimal Control, Prentice-Hall, Englewood Cliffs
2. Feng Lin, (2007), Robust Control Design: An Optimal Control Approach, Wiley
3. S. P. Bhattacharyya, H. Chapellat, and L.H. Keel, (1995), Robust Control: The Parametric Approach. Prentice-Hall

Relevant materials

Robust Control Toolbox help file (in MATLAB).

Title	**Foundations of Cyber-Physical Systems**	Number	**EEL4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0[3]
Offered for	B.Tech.	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Familiarize students with the concepts of Cyber-physical Systems (CPS).
2. Deliver the knowledge of CPS by focusing design and implementation.

Learning Outcomes

1. This course provides the knowledge of principles of operation and performance of CPS.
2. The student must be able to design and develop CPS for various industry applications.

Contents:

Introduction to Cyber-physical Systems [5 Lectures]: Basic principles of CPS; Industry 4.0, AutoSAR, IIOT implications; Building Automation, Medical CPS

CPS - Platform Components [5 Lectures]: CPS HW platforms - Processors, Sensors, Actuators; CPS Network - WirelessHart, CAN, Automotive Ethernet; Scheduling Real Time CPS tasks

Modelling and Control of CPS [10 Lectures]:
Synchronous and Asynchronous Model; Principles of Dynamical Systems (5L)
Hybrid Systems; Control and Sensing Techniques (5L)

CPS - Computational Issues [10 Lectures]:
Effect of scheduling, bus latency (5L)
Sense and actuation faults on control performance, network congestion. (5L)

Applications of CPS [4 Lectures]: Robot motion control; Autonomous Vehicle control; Smart Grid; Building Automation

Secure Deployment of CPS [8 Lectures]:
Threat model; Denial-of-Service (DoS) attacks and deception attacks (3L)
Attack detection, location and validation; Secure state estimator (5L)

Textbooks

1. Rajeev Alur, Principles of Cyber-Physical Systems, MIT Press, 2015.
2. Edward A. Lee and Sanjit A. Seshia, Introduction to Embedded Systems, A Cyber-Physical Systems Approach Second Edition, MIT Press, ISBN 978-0-262-53381-2, 2017.

Devices and Circuits

Title	**VLSI Design**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective Course
Prerequisite	Circuits, Basic understanding of electronics		

Objectives

The Instructor will :

1. Give overview of IC Technology and unit process
2. Teach students the basics of digital circuit design methods.
3. Provide the understanding of necessary concepts for digital VLSI design according to design rules decided by various technologies

Learning Outcomes

The students are expected to have the ability to:

1. Understand designing and optimizing digital circuits with different quality metrics: cost, speed, power dissipation, and reliability
2. Design the building blocks of digital systems

Contents

Introduction to VLSI Design, CMOS process sequence, fabrication and layout design rules [3 lectures]
Technology Scaling, Effect of Process variations [2 lectures]
Interconnect and wire models [2 lectures]
CMOS Inverter, Static and Dynamic Behaviour, Propagation delay, noise margins, and power dissipation [4 lectures]
Static timing analysis, delay estimation using logical effort and Elmore delay [4 lectures]
Designing combinational logic gates: Static CMOS design, Ratioed Logic, Pseudo NMOS, Pass Transistors Logic, design examples like multiplexers, decoders [4 lectures]
Dynamic CMOS design, speed and power dissipation, choosing a logic style, design examples like clock generation circuits [3 lectures]
Static Latches and Registers, Dynamic Latches and Registers, Alternative Register styles, pipelining, choosing a clock strategy [5 lectures]
Timing Issues in Digital Circuits: Timing classification, Synchronous Design, Synchronous timing basics, Skew and Jitter, clock distribution techniques [5 lectures]
Memory Classification, Building Blocks, Memory core, Read only Memory, Read-write Memories, Memory peripheral circuitry [5 lectures]
Decoders, Sense Amplifiers, Buffers, reliability, power dissipation, future trends validation and test [5 lectures]

Textbook

1. Rabaey, J. M., Chandrakasan, A., Nikolic, B., (2011), *Digital integrated Circuits, A design perspective, 2nd Edition, PHI Learning*
2. Weste N. H. E., Harris D. M. (2009), *CMOS VLSI Design*, 4th Edition, Pearson
3. Plummer J. D., Deal D. M., Griffin P. B., (2009) *Silicon VLSI Technology- Fundamentals, Practice And Modelling*, Pearson

Self-Learning Material

1. Chandorkar,A.N., VLSI Design, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Bombay, https://nptel.ac.in/courses/117/101/117101058/
2. Chandrakasan,A., MIT OpenCourseware, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-374-analysis-and-design-of-digital-integrated-circuits-fall-2003/

Title	**Biosensors**	Number	**EE3XX0**
Department	Electrical Engineering	L-T-P [E]	3–0–2 [4]
Offered for	B.Tech.	Type	Elective
Prerequisite	Fundamentals of Electrical and Bio Engineering		

Objectives

The Instructor will:

1. Make the students understand the fundamentals of working principles of biosensors
2. Describe the bio-specific interaction used for various applications
3. Evaluate and compare techniques used in today's time like electric, optical and mechanical
4. Show and explain the examples of practical and real world biosensors

Learning Outcomes

The students are expected to have the ability to:

1. Identify the working mechanism of biosensors
2. Understand the detailed characterization of biosensors in terms of specificity and selectivity
3. Comprehend the functioning of commercial biosensors
4. Create mechanisms for developing biosensors on their own by collaborating or working in an interdisciplinary group

Contents

Introduction to basics of sensors and biospecific interactions *[8 Lectures]:*
Introduction to sensors and actuators, different components of biosensors, functionalization layers and their importance (4L)
Biomolecules for biosensors, catalytic biosensors, affinity biosensors, biomolecular interaction (4L)
Electrical and optical techniques for biosensing *[8 Lectures]:*
Electrical - CV, ISFET (4L)
Optical - Fluorescence, ELISA, SERS, SPR (4L)
Electrochemical, mechanical and advanced techniques for biosensing *[11 Lectures]:*
Electrochemical (sub classifications like impedemetric, voltammetric, amperometric) (6L)
Mechanical (Bio-MEMS), color based, microfluidics (including packaging), AI based biosensors(5L)
Sensor key parameters and examples of commercially available biosensors *[7 Lectures]:*
Sensitivity, selectivity, response- and recovery time, LOD etc. (4L)
Industry standards and COTS bio-sensors and their functioning, need and relevance of biosensors in Indian context (3L)
Readout Electronics*[8 Lectures]:*
Basic circuitry to make readout electronics, Potentiostats, amperometric circuits, charge to voltage converter (4L)
Variable gain amplifier, low noise amplifier, high resolution and low noise data converters, mismatch insensitive data converters (4L)

Lab work:

Biosensor material selection and characterization; Biochemical reagents and assays; Surface functionalization (Covalent/non-covalent) for Biosensing; Biosensor fabrication; Biosensor operation and signal generation; Biosensor sensitivity assay; Biosensor reproducibility; Biosensor Selectivity; Determination of limit of detection; Use of appropriate controls; Biosensor application on real samples.

Textbook

1. Yoon J.-Y., (2016), *Introduction to Biosensors*, Springer
2. Banica F.-G., (2012), *Chemical Sensors and Biosensors: Fundamentals and Applications*, Wiley
3. Rasooly A., Herold K. E., (2008), *Biosensors and Biodetection*, Humana Press, Science

Self Learning Material

1. Materials for Biomedical Applications, MIT Open Courseware, https://ocw.mit.edu/courses/materials-science-and-engineering/3-051j-materials-for-biomedical-applications-spring-2006/lecture-notes/

Title	Biosensors	Number	EE3XX0
Course Title	**CAD for VLSI**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–2 [3]
Offered for	B.Tech.	Type	Elective
Pre-requisite	VLSI Design		

Objectives

The Instructor will:

1. Enable students to learn the concepts of computer aided design aspects of design of integrated circuits.
2. Provide exposure to the students about automating design cycle for VLSI Design.

Learning Outcomes

Students are expected to have the ability to:

1. Apply principles of CAD for VLSI for digital designs.
2. Implement the optimization algorithms for automated design of Analog circuits.

Contents

Introduction [2 Lectures]: Introduction to VLSI design methodologies and supporting CAD tool environment
VLSI Design Automation [5 Lectures]: Overview of System C; Schematic editors; Layout editors; Module generators; Placement and routing tools; Behavioral, functional, logic and circuit simulators
Algorithmic Techniques for Floor-planning [5 Lectures]: Algorithmic Techniques in VLSI CAD, Introduction of Floor planning, simulated annealing and mixed integer programming formulation
Placement and Partitioning [4 Lectures]: Classical placement algorithms, Simultaneous level partitioning based PDP (Power Delay Product)
Routing [3 Lectures]: General and Channel Routing, Global Routing, High-level power/current estimation.
Optimization based Analog Design [4 Lectures]: Analog Circuit Design Challenges, Performance metrics and trade-offs, Deterministic and metaheuristic optimization based automated design flows at transistor level.
Verilog-A [5 Lectures]: Introduction to Verilog-A, Basic functions and statements, User defined functions and systems tasks, Basic analog designs using Verilog-A.

Lab Experiments on algorithmic level design implementation, basic floorplanning and routing, High-level power estimation algorithms, Automation of Analog Circuit Design, Complex analog circuit design using optimization techniques, Verilog-A programming.

Text Books

1. Gerez,S.H., *Algorithms for VLSI Design Automation*. Wiley, 1998.
2. Sait,S.M., and Youssef,H., *VLSI Physical Design Automation*. World Scientific Publishing Company, 1999.
3. Fakhfakh,M., Esteban,T.-C., Siarry,P., *Computational Intelligence in Analog and Mixed-Signal (AMS) and Radio-Frequency (RF) Circuit Design*. Springer 2015.
4. Kundert,K.S., Zinke,O., *The Designer's Guide to Verilog-AMS*. Springer, June 2004.

Preparatory course material

1. Kamakoti,V., and Balachandran,S., CAD for VLSI, NPTEL Course Material, Department of Computer Science and Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/106106088/
2. Barros,M.F.M., Guilherme,J.M.C., Horta,N.C.G., *Analog Circuits and Systems Optimization based on Evolutionary Computation Techniques*. Springer, 2010.

Title	**Sensors and Actuators**	Number	**EE4XX0**
Department	Electrical Engineering	L-T-P [E]	3–0–0 [3]
Offered for	B.Tech. 4th Year	Type	Elective Course
Prerequisite	Material Science and Engg., Semiconductor Devices, Analog circuits		

Objectives

The Instructor will :

1. Make the students know about different types of sensors and materials for sensors
2. Use concepts for converting physical parameter into an electrical quantity
3. Explain sensor parameters, different packaging types and readout circuitry
4. Show and explain examples of sensors relevant to the industry

Learning Outcomes

The students are expected to have the ability to:

5. Identify the commercial and most used sensors in the industry
6. Understand the underlying sensing phenomena used in sensors
7. Develop a synthesis process and characterize a sensor on their own
8. Test and examine the sensor functioning and comprehend as to what needs to be developed

Contents

Introduction to Sensors and Actuators [10 Lectures]:
Different types of sensors, classification of transducers (6L)
Structure of a transducer and types of transducers (Fluidic actuators, Piezoelectric and piezoresistive actuators etc.) (4L)
Materials for sensors [6 Lectures]: Introduction to nanostructured materials, metal oxides, quantum dots, 2D materials
Parameters and characteristics of Sensors and Transducers [6 Lectures]: Sensor parameters like sensitivity, selectivity, response- and recovery time, stability, ageing, repeatability, drift, calibration
MEMS and transducers [6 Lectures]: MEMS structural elements, scaling advantages, transduction pathways, examples of electromechanical transduction
Different packaging for Sensors [4 Lectures]: Premould packaging, Moulded interconnect devices, Hermetic packaging, Wafer level packaging
Sensors readouts [5 Lectures]: Basic circuitry to read the data from sensors, Basic circuitry to read the data from sensors (noise, instrumentation amplifiers etc.)
Current trends in Sensing applications [5 Lectures]: Few examples of current sensors used in the industry and commercial sensors will be discussed

Textbook

1. Silva C. W. de, (2016), *Sensors and Actuators*, CRC Press
2. Zhang S., Li L., Kumar A., (2009), *Materials Characterization Technique*, CRC Press
3. Eggins B. R., (2007), *Chemical Sensors and Biosensors*, Wiley

Preparatory Course Material

Research articles such as ACS Nano Letters, IEEE Sensors, ACS Sensors, ACS Nano, Sensors & actuators B etc**.**

Title	**Physics and Modeling of MOS Transistor**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Physical Electronics		

Objectives

The Instructor will:

1. Provide in-depth understanding of the modeling of semiconductor devices

Learning Outcomes

The students are expected to have the ability to:

1. Understand the operation and modeling of MOS transistor
2. Develop models for novel semiconductor devices.

Contents

Fundamentals [8 Lectures]:

Intrinsic and extrinsic semiconductors, fermi and quasi fermi-level, charge-density, electric field and potential (4 Lectures), Gauss's law and Poisson's equation, mobility and scattering mechanism, drift and diffusion (4 Lectures)

Two Terminal MOS Cap [10 Lectures]:

Flatband voltage, potential and charge balance, accumulation/depletion/inversion (5 Lectures)

Weak/moderate/strong inversion, high and low frequency capacitance (5 Lectures)

MOS Transistors [15 Lectures]:

Three terminal MOS transistor, body effect (5 Lectures)

Four terminal MOS transistor, effect of drain voltage, transport: mobility, series resistance, impact of doping, capacitance behavior (5 Lectures)

Scaling, leakage current, impact ionization, short channel effects and optimization strategies (5 Lectures)

Noise and Equivalent Circuit [6 Lectures]:

Flicker, thermal and shot noise. Small signal equivalent circuit (3 Lectures)

Non-linearity and harmonic distortion, Non-quasi static effect (3 Lectures)

Nanoelectronics: Challenges and future prospective (3 Lectures)

Textbooks

1.Y. Tsividis. *Operation and Modeling of the MOS Transistor*. Oxford University Press; 3rd edition, 2010.

2.C. Hu, *Modern Semiconductor Devices for Integrated Circuits*. Pearson, 2009.

3.D. Neamen, *Semiconductor Physics And Devices*. McGraw Hill Education; 4th edition, 2017.

Self Learning Material

Prof. Karmalkar, *Semiconductor Device Modeling*, NPTEL Course Material, Department of Electronics & Communications Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117/106/117106033/

Preparatory Course Material

Prof. Karmalkar course, *Solid State Devices*, NPTEL Course Material, Department of Electronics & Communications Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117/106/117106091/

Computing Systems

Title	**Real Time Systems**	Number	**EEXX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0[3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Computer Architecture, Embedded System		

Objectives

The Instructor will:

1. Describe real-time systems and how real-time resource management algorithms and mechanisms to meet application timing constraints.
2. Explain how to conduct real-time schedulability analysis.

Learning Outcomes

The students are expected to have the ability to:

1. Use RTOS for different applications
2. Design system to meet different real time constraints in uniprocessor and multiprocessor Environment.

Contents:

Introduction of real time systems [4 Lectures]: Types of time constraints; definition of scheduling, examples of real time systems

Periodic Task Scheduling [6 Lectures]:

Timeline scheduling;Rate Monotonic scheduling; Earliest Deadline First (4L)

Deadline Monotonic EDF with constrained deadlines (2L)

Aperiodic task scheduling [4 Lectures]:

Jackson's algorithm; Horn's algorithm; Non-preemptive scheduling (2L)

Scheduling with precedence constraints (2L)

Fixed-priority servers [7 Lectures]:

Background scheduling; Polling Server Deferrable Server; Priority Exchange Sporadic Server (4L)

Slack stealing Non-existence of optimal servers; Performance evaluation (3L)

Dynamic priority servers [6 Lectures]:

Dynamic Priority Exchange Server; Dynamic Sporadic Server; Total Bandwidth Server; Earliest Deadline Late Server; Improved Priority Exchange Server (4L)

Improving TBS; Performance evaluation; The Constant Bandwidth Server (2L)

Limited pre-emptive scheduling [6 Lectures]:

Non-preemptive scheduling; Preemption thresholds (4L)

Deferred Preemptions; Task splitting (2L)

Real-time operating systems and Standards Standards for real-time operating systems; Commercial real-time systems; [6 Lectures]

Linux related real-time kernels; Open-source real-time research kernels [3 Lectures]

Textbooks

1. G. C. Buttazzo (2011), 2/e, Hard Real Time Computing Systems; Springer.
2. Phillip A. Laplante (2004), 3/e, Real Time Systems Analysis and Design, IEEE Press.

Course Title	**Reconfigurable Computing**	Number	**EEL4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Compulsory
Pre-requisite	Digital Design		

Objectives

The Instructor will:

1. Enable students to learn the concepts of reconfigurable computing.
2. Provide exposure to the students about reconfigurable architectures and their programming for system level designs.

Learning Outcomes

Students are expected to have the ability to:

1. Apply principles of reconfigurable computing for digital system design.
2. Implement the basic computing architectures using reconfigurable computing platforms.

Contents:

Reconfigurable Computing: Introduction to Reconfigurable Computing, Need of Reconfigurable Computing, Historical perspective in terms of system design. (3 Lectures)

Reconfigurable Architectures: Introduction to Field Programmable Gate Array (FPGA) Technology, FPGA Arithmetic, Applications. (4 Lectures)

The Systolic Model, Runtime Reconfigurable Architectures: PipeRench. (3 Lectures)

Runtime Reconfigurable Architectures: Multi-Context, Function-Unit Architectures. (4 Lectures)

Reconfigurable Programming: Logic Emulation Architectures, Programming Reconfigurable Computers, Logic Cell and Datapath Mapping. (4 Lectures)

Behavioral Synthesis, Hardware/Software Co-design, Systolic Loop Transformations. (5 Lectures)

Software Pipelining, Retiming, Module Generators. (5 Lectures)

Reconfigurable Designs: Placement, Routing, Dynamically Reconfigurable Adaptive Viterbi Decoder. (4 Lectures)

Network Virtualization using Reconfigurable Hardware, Security for Reconfigurable Hardware in the Cloud, Partitioning. (5 Lectures)

High Level Compilation, Power Reduction Techniques, Soft GPGPUs on an FPGA, Hybrid FPGA Networks-on-Chip. (5 Lectures)

Text Books

1. Bobada,C, *Introduction to Reconfigurable Computing*. 1st edition, Springer, 2007.
2. Cardoso,J. and Hubner,M., *Reconfigurable Computing*. Springer-Verlag, 2011.

Preparatory course material

1. Tessier,R., Pocek,K. and DeHon,A., "Reconfigurable Computing Architectures," *Proceedings of the IEEE*, vol. 103, no. 3, pp. 332-354, March 2015.
2. Todman,T.,J. et al., "Reconfigurable computing: architectures and design methods,", *IEE Proceedings - Computers and Digital Techniques*, vol. 152, no. 2, pp. 193-207, March 2005.

Power Engineering

Title	**Power System Analysis and Stability**	Number	**EE4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Electrical Machines, Power Engineering		

Objectives

The Instructor will:

Provide the capability to understand and analyze various phenomena associated with power systems both under steady state and transients

Learning Outcomes

The students are expected to have the ability to:

Model the power system and determine various parameters, system status during normal and abnormal conditions

Contents

Load flow studies [10 Lectures]: Load flow problem: Ybus formulation (1L), Gauss-Seidel (5L), Newton- Raphson methods (3L), and decoupled power flow (1L)

Short circuit studies [12 Lectures]: Zbus formulation (2L), symmetrical and unsymmetrical faults, symmetrical components and sequence networks (5L), analysis of symmetrical and unsymmetrical faults (5L)

Power system stability [6 Lectures]: Definitions of stability problems, types of stability issues, swing equation, and swing curve, transient and small signal stability analysis of a single machine infinite bus system (5L), solution for swing equation (1L)

Power system monitoring and protection [8 Lectures]: Current and potential transformers, introduction to SCADA, synchro-phasors (PMU) (3L), introduction to protective relaying, types of relays and introduction to circuit breakers (5L)

Power system transients [6 Lectures]: Traveling waves and propagation of surges, overvoltage, lightning (5L), neutral grounding (1L)

Textbook

1. Stevenson,W.D.Jr., (1982), *Elements of Power System Analysis*, 4th Edition, McGraw Hill International
2. Wadhwa,C.L., (2010), *Electrical Power Systems*, 6th Edition, New Age International Publishers
3. Kothari,D.P., Nagrath,I.J., (2008), *Power System Engineering*, 2nd Edition, McGraw Hill Education (India) Private Limited

Self Learning Material

1. Sinha, A.K., *Power System Analysis,* NPTEL Course Material, Department of Electrical Engineering, IIT Kharagpur, https://nptel.ac.in/courses/108/105/108105067/
1. Das, D., *Power System Analysis,* NPTEL Course Material, Department of Electrical Engineering, IIT Kharagpur https://nptel.ac.in/courses/117105140/

Title	**Power System Operation and Control**	Number	**EE4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Electrical Machines, Power Engineering, Power System Analysis and Stability		

Objectives

The Instructor will:

Provide fundamentals of operation and control strategies needed for economic, efficient and reliable operation of power system

Learning Outcomes

The students are expected to have the ability to:

Understand and develop methods to optimize generation scheduling and maintain security of a power system

Contents

Characteristics of power generation units [5 Lectures]: Operational and economical aspects of thermal units, combined cycle units, nuclear units and hydro units

Economic dispatch [3 Lectures]: Definition of economic dispatch problem and various methods of economic dispatch

Transmission losses [3 Lectures]: Incremental losses and penalty factors, B matrix loss formula

Unit commitment [5 Lectures]: Introduction to unit commitment, constraints in unit commitment, unit commitment methods with and without constraints

Hydrothermal coordination [5 Lectures]: Hydroelectric plant models, hydrothermal coordination, methods of hydro-scheduling

*Active power generation control [5 Lectures]:*Modeling of generator, governor, prime mover and tie-line, automatic generation control in single area and multiarea power system

Power system security [5 Lectures]: Factors affecting power system security, contingency analysis, sensitivity factors

State estimation in power system [5 Lectures]: State estimation methods- weighted least squares, orthogonal decomposition, applications of state estimation

Optimal power flow [6 Lectures]: Solution of optimal power flow, sensitivity analysis (3L), security constrained optimal power flow (3L)

Textbook

1. Wood,A.J., Wollenberg,B.F., (2011), *Power Generation, Operation and Control*, Wiley-India edition
2. Wadhwa,C.L., (2010), *Electrical Power Systems*, 6th Edition, New Age International Publishers.
3. Kothari,D.P., Nagrath,I.J., (2009), *Modern Power System Analysis*, 3rd Edition, Tata McGraw Hill Education Private Limited

Self Learning Material

1. Das,D., *Power System Engineering,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kharagpur,https://nptel.ac.in/courses/108105104/

Title	**Power Electronics**	Number	**EE4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Physical Electronics		

Objectives

The Instructor will:

Provide fundamentals of power electronic circuits and applications

Learning Outcomes

The students are expected to have the ability to:

Design and analyze various types of converter circuits for applications in AC as well as DC circuits

Contents

Review of power electronic switches: Review of diode, BJT, MOSFET, IGBT as switching devices (2 lectures)

Controlled rectifiers: SCR switching circuits, protection, series and parallel operation (2 lectures), single phase controlled rectifiers with R, R-L, R-L-E load, effect of source inductance (3 lectures), three phase rectifiers (3 lectures), dual converters, power factor, and harmonics in single phase and three phase rectifiers (2 lectures)

AC voltage controller: Principle of ON-OFF and phase control (2 lecture), single phase and three phase controllers (3 lectures), cycloconverter (2 lectures)

DC-DC converters: Step-up and step-down converters with various type of loads (2 lectures), buck, boost, buck-boost and cuk regulators, isolated DC-DC converters (5 lectures)

Power Supplies: Introduction to switched-mode, resonant and bidirectional AC and DC power supplies (4 lectures)

Inverters: Principle of operation, single-phase and three-phase bridge inverter, 120° and 180° conduction (5 lectures), PWM inverters, current source inverters, space-vector-modulation (5 lectures)

Other converter topologies: PWM rectifiers, dual active bridge topology, introduction to multilevel inverters (2 lectures)

Textbook

1. Rashid,M.H., (2004), *Power Electronics Circuits, Devices, and Applications*, 3rd Edition, Pearson Education Inc.
2. Hart,D.W., (2011), *Power Electronics*, Tata McGraw-Hill Education Private Limited.
3. Mohan,N., (2007), *First Course on Power Electronics and Drives*, MNPERE.

Self Learning Material

Bhuvaneswari,G., *Power Electronics,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi,
https://nptel.ac.in/courses/108/102/108102145/

Title	**Industrial Drives**	Number	**EE4XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Electrical Machines, Power Electronics		

Objectives

The Instructor will:

Provide an understanding of the various AC and DC drives along with the various converter topologies used and their control used in industry

Learning Outcomes

The students are expected to have the ability to:

Design and develop various power electronic drives along with their control

Contents

Fundamentals of electric drives: Factors affecting selection of drives, speed-torque characteristics of motors and loads, characteristics and operating modes of drive motors (3 lectures), starting, braking and speed control of motors, 4 quadrant drives (3 lectures)

DC motor drives: Characteristics, starting methods, braking methods, speed control using converters and choppers (5 lectures), full converter, semi converter and dual converter fed DC drives (3 lectures)

Three phase induction motor drives: Starting methods, braking methods, speed control of cage rotor induction machines using AC voltage controllers, voltage-source and current-source inverters (5 lectures), V-by-f control and other control techniques, speed control of wound-rotor induction machines, slip-power recovery scheme (5 lectures), field oriented control and direct torque control of AC motors (2 lectures)

Three phase synchronous motor drives: Starting methods, braking methods (5 lectures), speed control methods (3 lectures)

Special machines and their drives: Permanent magnet brush-less motor drives, permanent magnet synchronous motor drives (3 lectures), stepper, reluctance motor drives and AC and DC traction drives (5 lectures)

Textbook

1. Dubey,G.K., (2001), *Fundamentals of Electrical Drives*, 2nd Edition, Alpha Science International Ltd
2. De,N.K., Sen,P.K., (1999), *Electrical Drives*, Prentice Hall of India Pvt Ltd
3. Vas,P., (1998), *Sensorless Vector and Direct Torque Control*, Oxford University Press

Self Learning Material

Das,S.P., *Fundamentals of Electric Drives,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur,
https://nptel.ac.in/courses/108/104/108104140/

Title	**Measurement and Instrumentation**	Number	**EEL3XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Introduction to Electrical Engineering		

Objectives

The Instructor will:

Provide an understanding of the constructional details and principle of operation of basic measuring instruments

Learning Outcomes

The students are expected to have the ability to:

Understand the operation of various measuring devices and choose the appropriate measuring device for measurement of different parameters

Contents

Measurement of Electrical Quantities: Voltmeter, ammeter, and ohmmeter, moving coil instruments (3 lectures), moving iron instruments, AC and DC measurements (4 lectures)

Power and Energy Measurement: DC and AC power measurement, low power factor wattmeter, power measurement in three-phase circuits (3 lectures), reactive power measurement, energy meters, theory and operation, compensation, power factor meter (4 lectures)

Instrument Transformers: Current and potential transformers (5 lectures)

Measurement of Electrical Elements: Measurement of medium, low and high resistances (3 lectures), AC bridges, inductance and capacitance measurement (4lectures)

Electronic Measurements: Electronic instruments for current, voltage and power measurement (5 lectures), Cathode ray oscilloscope, frequency and phase angle measurements using CRO spectrum (3 lectures)

Instrumentation: Transducers, classification & selection of transducers, strain gauges, inductive & capacitive transducers (4 lectures), piezoelectric and Hall-effect transducers, thermistor, thermocouple, encoder (4 lectures)

Textbook

1. Shawney,A.K., (2007), *A Course in Electrical and Electronic Measurements and Instrumentation*, 18th edition, Dhanpat Rai & Co. (P) Ltd.
2. Helfrick,A.D., Cooper,W.D., (2015), *Modern Electronic Instrumentation & Measurement Techniques*, Pearson Education India

Specializations

Communication Engineering Specialization

Title	**Wireless Communications**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.-Ph.D. Dual Degree (Comm. Engg.)	Type	Compulsory
Prerequisite	Fundamentals of Communications		

Objectives

The Instructor will:

1. Provide students an understanding of the concepts related to communication over wireless fading channel.
2. Expose students to concepts and techniques for exploiting fading and application of these concepts in multiuser communication systems context.

Learning Outcomes

The students are expected to have the ability to:

1. Understand concepts related to deep fade, diversity techniques and channel capacity for point-to-point wireless communications systems.
2. Analyze multi-user networks and understanding of techniques like opportunistic communication, multiuser diversity, superposition coding and successive interference cancellation.
3. Analyze and design wireless ad-hoc networks with special emphasis on energy constrained networks

Contents

Wireless Channels [10 Lectures]:

Review of signal detection over AWGN channels and M-ary Modulation (5L)

Modelling of wireless channels; space, time and frequency channel coherence; input/output channel models for single and multi-antenna systems (5L)

Diversity Techniques [12 Lectures]:

Digital modulation and its performance in fading (4L)

Deep fade and diversity (3L)

Realizing diversity: time diversity, frequency diversity, antenna diversity (5L)

Wireless Channel Capacity [10 Lectures]:

Capacity of the Gaussian channels (2L)

Outage limited and ergodic capacity of fading channels (4L)

Waterfillingalgorithm and opportunistic communication (4L)

Multiuser system design [10 Lectures]:

Multiple access and random access techniques (5L)

Multiuser channel capacity and multiuser diversity (5L)

Textbook

1. Tse, D. and Viswanath, P., (2005), Fundamentals of wireless communication, Cambridge University Press.
2. Goldsmith, A., (2005), Wireless Communications, Cambridge University Press.
3. Simon, M. K. and Alouini, M. S., (2004), Digital communication over fading channels, John Wiley and Sons.

Self-Learning Material

1. Zheng, L., Principles of Wireless Communications, MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-452-principles-of-wireless-communications-spring-2006/index.htm

Preparatory Course Material

Jagannatham, A. K., Principles of Communication II, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104098/

Title	**Digital Communications: Hands-on**	Number	**EEP7XX0**
Department	Electrical Engineering	L-T-P[C]	1–0–2 [2]
Offered for	B. Tech., M. Tech.	Type	Core
Prerequisite	Communication Systems		

Objectives

The Instructor will:

Provide students with hands-on exposure towards the design and implementation of digital communication systems using software defined radio technology.

Learning Outcomes

The students are expected to have the ability to:

1. Design communications systems by assessing the design trade-offs and real-world communication requirements
2. Utilize fundamental communication techniques such as CDMA and multicarrier modulation like OFDM for the current and future wireless networks relevant to industry needs.

Contents

Lecture:

Introduction to programmable hardware, Software Architecture, USRP hardware, signal processing chain, channel modeling, estimation and equalization, fading and diversity, carrier and symbol synchronization, multicarrier modulation, CDMA

Laboratory:

Lab 1: Setting up the programmable hardware to transmit and receive signals
Lab 2: Estimating signal power, noise power, the power spectrum, and the bandwidth of Signals
Lab 3: Sampling, aliasing, interpolation, resampling, upsampling, and downsampling
Lab 4: Dealing with narrowband channel impairments: synchronization and channel estimation
Lab 5: Implementation of a transmitter and receiver using programmable hardware
Lab 6-7: Receiver Structure & Waveform Synthesis of a Transmitter and a Receiver
Lab 8-9: Implementation of multicarrier modulation like OFDM and synchronization using programmable hardware
Lab 10: Implementation of Spectrum Sensing Techniques
Lab 11-14: Term project

Textbook

Pu, D. and Wyglinski, A. M. (2013), *Digital Communication System Engineering with Software-Defined Radio*, 1st Edition, Artech House

Self Learning Material

Wyglinski, A. M., *Software Defined Radio Systems and Analysis,* Online Course Material, Department of Electrical and Computer Engineering, Worcester Polytechnic Institute, https://www.youtube.com/playlist?list=PLBfTSoOqoRnOTBTLahXBlxaDUNWdZ3FdS

Title	**UAV Assisted Wireless Networks**	Number	**EEL7XX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech and Ph.D.	Type	Elective
Prerequisite	Wireless Communications		

Objectives

The Instructor will:

Provide a comprehensive overview of wireless communication and networking with UAVs.

Learning Outcomes

The students are expected to have the ability to:

Perform channel modeling for UAV-BSs and UAV-UEs, design and optimization of their deployment, trajectory, multiple access, and resource management.

Contents

*UAV Applications and Use Cases [5 lectures]:*IoT systems, Wireless backhauling for ground systems, three-dimensional MIMO

Basic Theoretical Background [10 Lectures]:

Aerial channel modelling and waveform design (5L)

Network architectures, disruption-tolerant airborne network protocols (5L)

UAV Assisted Cellular Communications [18 Lectures]:

Deployment of UAV base stations for optimized coverage (5L)

UAV network modelling (5L)

Downlink performance analysis for UAV base station (5L)

Resource management(3L)

Cellular Assisted UAV Sensing [9 Lectures]:

Cooperative communication in UAV networks (5L)

Security of UAV UEs (4L)

Textbook

1. Namuduri, K., Chaumette, S., Kim, J., and Sterbenz, J., (2017), UAV Networks and Communications, Cambridge University Press
2. Saad, W., Bennis, M., Mozaffari, M., and Lin, X., (2020), Wireless Communications and Networking for Unmanned Aerial Vehicles, Cambridge University Press

Self Learning Material

Best Readings in UAV Assisted Wireless Networks, IEEE

https://www.comsoc.org/publications/best-readings/uav-assisted-wireless-networks

Preparatory Course Material

Jagannatham, A. K., Principles of Communication II, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104098/

Title	**Optical Signal Processing**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Elective
Prerequisite	Semiconductor Physics, Electromagnetism and Optics		

Objectives

The Instructor will:

1. Introduce the basics of nonlinearities in optical devices and how they can be harnessed for processing of light waves.
2. Explain the working, modeling and characterization of various optical signal processing devices along with their advantages and limitations.

Learning Outcomes

The students are expected to have the ability to:

1. Design, characterize and analyze basic optical signal processing circuits.
2. Appreciate the advantages of optical signal processing over conventional electronic signal processing techniques.

Contents

Nonlinear Optics for Signal Processing [8 Lectures]:
Nonlinear optical susceptibility, time-domain description of optical nonlinearities (4L),
Kramers-Kronig relations, intensity dependent refractive index of materials (4L)
Third Order Nonlinearities [18 Lectures]:
Theory and modeling of Optical Kerr Effect (2L),
Self Phase Modulation and Cross Phase Modulation processes (4L),
Optical phase conjugation, Four Wave Mixing and Third Harmonic Generation (5L),
Photon-phonon interaction, Stimulated Brillouin, Raman and Rayleigh scattering (5L),
Two Photon Absorption (2L)
Optical Signal Processing Devices [16 Lectures]:
Optical Fourier Transform (2L),
Optical correlators (2L),
Pulse compression, pulse shaping (4L),
Optical interconnects (2L),
Multiplexers, mixers, wavelength conversion (4L),
Tunable optical delay (2L)

Textbooks

1. Boyd, R. W., (2013), *Nonlinear optics*. Elsevier.
2. Dragoman D., and Dragoman M. (2013), *Advanced optoelectronic devices*. Vol. 1. Springer Science and Business Media..
3. Saleh, B.E.A, and Teich M.C., (1991), *Fundamentals of photonics*. Vol. 22. New York: Wiley.

Self-Learning Material

Singh B.P and Rustagi K.C., *Nonlinear Optics,* NPTEL Course Material, Department of Physics, Indian Institute of Technology Bombay,
https://nptel.ac.in/courses/115/101/115101008/

Preparatory Course Material

Roy S., *Introduction toNonlinear Optics and its Applications,* NPTEL Course Material, Department of Physics, Indian Institute of Technology Kharagpur,
https://nptel.ac.in/courses/115/105/115105105/

Title	**Optical Networks**	Number	EE7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech,Ph.D	Type	Elective
Prerequisite	Basics of Fiber Optic communications		

Objectives

The Instructor will:

1. Introduce elements and components of an optical networking solution.
2. Explore the capabilities and limitations of different network topologies.

Learning Outcomes

The students are expected to have the ability to:

1. Identify the required network technology for a given requirement.
2. Solve WDM network design problems.

Contents

Introduction to Optical Networks: Types of traffic, Services, Optical packet and circuit switching, Optical Layered Architecture. Optical Network elements [5 lectures]

Local Area Network: Network topologies, Multiplexing and Multiple access techniques [4 lectures], Network resource sharing, Network capacity, Protocols. [4 lectures]

Optical Access Networks: Passive Network Topology, PON architecture [3 lectures], Multi point control protocol, Dynamic bandwidth allocation, FTTx networks [5 lectures]

Metropolitan and Wide Area Networks: SONET/SDH, Optical Transport Network [3 lectures], Wavelength Routing Network, Routing and Assignment Algorithm. [5 lectures]

Network Control, Management and Survivability: Network management system architecture, Functionality, GMPLS [3 lectures], Impairment, Survivability, Protection and Restoration. [5 lectures]

Free-Space Optical Networks: Classification, FSO network topologies, Design factors, FSO Network applications. [5 Lectures]

Textbooks

1. Chadha D. (2019), *Optical WDM networks: from static to elastic networks*, Wiley-IEEE Press.
2. Grobe K. and Eiselt M. (2013), *Wavelength Division Multiplexing, A Practical Engineering Guide*, Wiley.
3. Ramaswami R., Sivarajan K.N. and Sasaki G.H. (2010), *Optical Networks: A Practical Perspective*, 3rd Edition, Morgan Kaufmann Publishers.

Preparatory Course Material

Keiser G. (2013), *Fibre Optic Communication*, McGraw-Hill, 5th Edition.

Title	**Optical Techniques for Communications**	Number	EE-4XX0
Department	Electrical Engineering	L-T-P [C]	2–0–2 [3]
Offered for	B. Tech.	Type	Elective
Prerequisite	Basic EM Theory		

Objectives

The Instructor will:

Introduce light propagation methods and techniques such as OAM Multiplexing, spatial filtering and Holography useful for future communication systems.

Learning Outcomes

The students are expected to have the ability to:

Work with optical components and design basic optical setups such as a free-space optical link, interferometer, beam analysis, imaging and Holography.

Course Content

Propagation Techniques: Ray propagation through optical components (mirrors, lenses, beam splitters) [4 lectures], Propagation characteristics of Gaussian, LG and HG beams [5 lectures], OAM content, OAM generation, OAM Data multiplexing [3 lectures].

Interferometry and Holography: Coherence, Michelson and Mach-Zehnder Interferometer, Polarization concepts [4 lectures]. Optical Fourier Transform, Diffraction, 4-f Imaging system, Spatial filtering [4 lectures]. Holographic recording and reconstruction, Recording material [5 lectures], Holographic Interferometry [3 lectures]

Lab Experiments will be conducted on collimation, beam expansion, beam analysis, interference phenomenon and applications, polarization effects, Imaging and Hologram generation.

Textbooks

1. Saleh, B. E. A., and Teich, M. C., (2007) *Fundamentals of Photonics*, John Wiley & Sons.
2. Thomas K., (2005), *Handbook of holographic interferometry- optical and digital methods*, Wiley-VCH.
3. Hariharan P., (2002) *Basics of Holography*, Cambridge University Press.

Self-Learning Material

Bhattacharya S., Optical Engineering, NPTEL, Department of Electrical Engineering, IIT Madras, https://nptel.ac.in/courses/108/106/108106161/

Title	**RF system design for Communications**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. - Year	Type	Elective
Prerequisite	Engineering Electromagnetics, Microwave Circuits		

Objectives

The Instructor will:

1. Familiarize behavior of cascaded blocks in RF system and effect of specification of blocks on system performance
2. Provide basic understanding about behavior of intermodulation products, spurious responses
3. Provide basic understanding of linearity of a system

Learning Outcomes

The students are expected to have the ability to:

1. Formulate and analyse system specification to control gain requirement, noise figure of the system.
2. Obtain basic understanding of linearity of a cascade from specifications on its modules.
3. Obtain basic understanding of the spurious responses in a conversion scheme

Contents

Introduction to Wireless Circuit Design: Radio Channel and modulation requirements, bits, symbols and waveforms, wireless system building blocks, system specification and their relation to circuit design- system noise and noise floor, System amplitude and phase behaviour, introduction to MIC- amplifier & oscillator (5 lectures)

*Gain:*S, T and X parameter, Module Gain, Overall Response, Standard Cascade, Bilateral Modules(4 lectures)

*Interconnections:*Lossy Interconnections, Nonstandard Impedances, Sensitivities(3 lectures)

Noise Figure: Noise Factor and Noise Figure, Cascaded module- applicable gain & noise figure, Impedance-Dependent Noise Factors, Image Noise-Mixers, Extreme Mismatch-Voltage Amplifiers, Gain Controls(5 lectures)

Nonlinearity: Representing Nonlinear Responses, 2^{nd} and 3^{rd} order terms, Frequency Dependence, Cascades-intermodulation products (IM) Adding Coherently and randomly (4 lectures)

*Intermodulation:*Anomalous IMs, Measuring IMs, Intermodulation of Noise, Composite Distortion, optimizing cascades(4 lectures)

Linearity improving architecture: Parallel Combining- hybrid, push-pull, Combiner Trees, Feedback, Feedforward - Intermods and Harmonics, Nonideal Performance(5 lectures)

Contaminating Signals: Frequency conversion basics, Spurs, Two-Signal IMs, Hard& soft Limiting(3 lectures)

*Mixer:*Mixers Through the LO Port - AM Suppression, FM Transfer, Single-Sideband Transfer, Mixing Between LO Components(4 lectures)

Phase noise- Jitter, Receiver Desensitization, Sources of Phase Noise, Processing Phase Noise in a Cascade, Determining the Effect on Data(5 lectures)

Textbook

1. William Egan, (2003), Practical RF System Design, by William Egan, 6^{th} Edition, John Wiley & Sons
2. Ulrich L. Rohde, David P. Newkirk, (2000), RF/ Microwave Circuit design for wireless applications, John Wiley & Sons

Self Learning Material

Kumar P., RF Integrated Circuits, Department of EE, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117102012/#

Preparatory Course Material

Bhattacharjee R., Microwave Engineering, Department of EEE, Indian Institute of Technology Guwahati, https://swayam.gov.in/nd1_noc19_ee68/preview

Title	**RADAR Engineering**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. ,M.Tech.	Type	Elective course
Prerequisite	Basics of RF circuits, Fundamentals of Communication Systems		

Objectives

The Instructor will :

1. Teach the fundamentals RADAR.
2. Teach building blocks and different types of RADAR.

Learning Outcomes

The students are expected to have the ability to:

1. Understand the building blocks and working principles of RADAR.

Contents

Introduction: Working principle, RADAR range equations, maximum unambiguous range, pulse repetition frequency, radar block diagram. (5 lectures)

Detection: Probability of detection, False alarm, radar cross section of targets. (3 lectures)

Types of RADAR:Pulse radars and CW radars, MTI RADAR, Doppler effect, delay-line cancellers, blind speeds. (5 lectures)

Moving target and tracking: Moving target detector, limitations of MTI, tracking with radar, monopulse tracking, conical scan. (5 lectures)

RADAR measurements: RADAR measurement and accuracy, Range and velocity ambiguities, the ambiguity diagram. (4 lectures)

Pulse shaping: Pulse compression-principles, matched filter, chirp waveforms. (4 lectures)

Clutter: Descriptions of land & sea clutter, detection of targets in clutter. (4 lectures)

RADAR antenna: Requirements of RADAR antenna, antenna parameters, reflector antennas, scanning phased array antennas, diplexing antenna. (5 lectures)

RADAR receiver: Receiver architecture, heterodyne receiver, noise figure. (4 lectures) *Transmitter:* Transmitter architecture, isolation between transmitter and receiver, duplexers. (3 lectures)

Textbook

1.Skolnik M.I., (2017), *Introduction to RADAR systems*, 3rd Ed., McGraw Hill.
2.Richards M.A., (2005), *Fundamentals of RADAR signal processing*, Indian Ed., McGraw Hill.
3.Carpentier M.H., (1988), *Principles of modern RADAR systems*, Artech house publishers.

Self Learning Material

O'Donnell R.M. , *Introduction to RADAR systems*, MIT open course, MIT Lincoln Laboratory, https://ocw.mit.edu/resources/res-ll-001-introduction-to-radar-systems-spring-2007/

Intelligent Communication and Networking Specialization

Title	**Design and Analysis of Communication Networks**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–2 [4]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Compulsory
Prerequisite	Data and Computer Communications, Signals and Systems		

Objectives

The Instructor will:

Provide in-depth understanding of communication network analysis, modeling and simulation techniques.

Learning Outcomes

The students are expected to have the ability to:

1. Analyse and evaluate communication networks using analytical and simulation-based methods including traffic models, graph models and mobility models.
2. Design and program software components for network simulations and analysis.

Contents

Probabilistic models for communication systems [10 Lectures]:

Linear System with Random process Input (4L)

LTI System with WSS Process Input, point-to-point communications link (2L)

multi-point links, random and multiple access techniques (4L)

Modelling and Analysis of Communication Networks [16 Lectures]:

Random number generation, mobility models (3L)

Channel models, topology models, graph theory and algorithms (5L)

Queuing models, queuing networks (5L)

Network calculus (3L)

Simulation of Communication Networks [16 Lectures]:

Discrete event-based simulation (3L)

Monte-carlo simulation(4L)

Rate-based simulation (3L)

*A*nalysis of simulation results, statistical analysis (4L)

Visualization of results (2L)

Lab Experiments will be conducted on traffic modeling, link-level, system-level, packet level simulation, SW/HW in the loop.

Textbooks

1. Srikant, R. and Ying, L., (2014), Communication Networks: An Optimization, Control and Stochastic Networks Perspective , Cambridge University Press.
2. Kumar, A., Manjunath, D. and Kuri, J., (2004), Communication Networking: An Analytical Approach, Morgan Kaufman Series in Networking, (an imprint of Elsevier Science)
3. Bonald, T. and Feuillet, M., (2011), Network Performance Analysis, Wiley.

Reference Book

Law, A. M., (2015), Simulation Modeling and Analysis, Fifth Edition, McGraw-Hill.

Self Learning Material

Scalable Wireless Ad-hoc Network Simulator, http://jist.ece.cornell.edu/index.html

Preparatory Material

Modiano, E., *Data Communication Networks,* MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-263j-data-communication-networks-fall-2002/index.htm

Title	**Intelligent Radio Networks**	Number	**EEL7XX0**
Department	Electrical Engineering/ Computer Science and Engineering	L-T-P [C]	3–0–2 [4]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Compulsory
Prerequisite	Pattern Recognition and Machine Learning, Data and Computer Communications		

Objectives

The Instructor will:

Provide understanding of the intricacies involved in making intelligent and cognitive radios work.

Learning Outcomes

The students are expected to have the ability to:

Use intelligent techniques to address the challenges and trade-offs in cognitive radio networks

Contents

Introduction to Software defined radios (SDR) [6 lectures]:

Spectrum scarcity, Spectrum white space, Fixed spectrum allocation [3L],

Software defined radio (SDR), Limitations of SDR [3L].

Cognitive radios [6 lectures]:

Introduction, Evolution, Concept, Dynamic spectrum access, Cognitive cycle [3L],

Functions, spectrum sensing, spectrum management, spectrum mobility, Cognitive radio architecture [3L].

Software Defined Networking [10 lectures]:

Evolution, operation, applications [5L],

Open flow specifications, network function virtualization [5L].

Cognitive Radio Networking [15 lectures]:

MAC layer for CRN, routing models in CRN [5L],

Cross layer considerations: impact on upper layer protocol design, trade-offs[10L].

Intelligent radio and Intelligent Radio Networking [10 lectures]:

Intelligent techniques for spectrum sensing, spectrum access and spectrum sharing [5L],

Use of AI and ML in network management, applications and services [5L].

Laboratory:

Introduction to MATLAB, GNU Radio and USRP platform, Simulate CR/IR network in MATLAB, Centralized cooperative spectrum sensing in CRN using ns3, Experiments with WiFi based WLAN MAC protocols

Textbooks

1. Xiao, Y., and Hu, F. (2008), *Cognitive radio networks*, 1st Edition, CRC press.
2. Göransson, P., Black, C. and Culver, T. (2016), *Software Defined Networks: A Comprehensive Approach,* 2nd Edition, Morgan Kauffman.

Self-Learning Material

1. Rawat, M., *Basics of Software Defined Radio and Practical Applications,* NPTEL Course Material, Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee, https://nptel.ac.in/courses/108/107/108107107/
2. K. B. Letaief, W. Chen, Y. Shi, J. Zhang and Y. A. Zhang, "The Roadmap to 6G: AI Empowered Wireless Networks," *IEEE Communications Magazine*, vol. 57, no. 8, pp. 84-90, August 2019.
3. Relevant recent research papers in the field.

Preparatory Material

Modiano, E., Data Communication Networks, MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-263j-data-communication-networks-fall-2002/index.htm

Title	**Computation Oriented Communications**	Number	**EEL7XX**
Department	Electrical Engineering and Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Elective
Prerequisite	Pattern Recognition and Machine Learning, Data and Computer Communications		

Objectives

The Instructor will:

Introduce the area of computation oriented communications

Learning Outcomes

The students are expected to have the ability to:

Design communication networks for federated learning

Contents

Resources for Communication networks for distributed computing [6 Lectures]
Federated Learning [6 Lectures]
Edge Intelligence and distributed computation [6 Lectures]
Rate-latency-reliability tradeoff[6 Lectures]
Network Intelligence [6 Lectures]
Communication network design and implementation for federated learning [6 Lectures]
Application aware communication for IoT devices [6 Lectures]

Textbook

Self Learning Material

1. Konečný J., McMahan, H.B., Yu, F. X., Richtarik, P., Suresh, A. T., and Bacon, D., Federated Learning: Strategies for Improving Communication Efficiency, NIPS Workshop on Private Multi-Party Machine Learning 2016.
2. Bennis, M., Debbah, M. and Poor, H. V., "Ultrareliable and Low-Latency Wireless Communication: Tail, Risk, and Scale," in Proceedings of the IEEE, vol. 106, no. 10, pp. 1834-1853, Oct. 2018
3. Machine Learning For Communications Emerging Technologies Initiative, IEEE https://mlc.committees.comsoc.org/research-library/

Title	**Machine Learning for Communications**	Number	EEL7XXX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., Ph.D.	Type	Elective
Prerequisite	Pattern Recognition and Machine Learning, Data and Computer Communications		

Objectives

The Instructor will:

Introduce the area of machine learning in the context of communications

Learning Outcomes

The students are expected to have the ability to:

Apply machine learning techniques to various signal processing requirements for communications including channel estimation, automatic modulation classification and iterative channel decoding.

Contents

Channel estimation and prediction [14 Lectures]:

Adaptive transmission systems, The Impact of Outdated CSI, Classical Channel Prediction, Neural Network Based Prediction Schemes (5L)

Flat fading SISO Prediction, Channel-Gain Prediction with Real-Valued and Complex-Valued RNN, Channel Envelope Prediction, Frequency-Selective SISO Prediction (5L)

Performance and Complexity, Computational Complexity (4L)

Automatic Modulation Classification [10 Lectures]:

Signal Models for modulation classification (2L)

Likelihood based classifiers (2L)

Distribution Test-based classifiers (2L)

Modulation classification Features (2L)

Machine Learning models for Modulation classification (2L)

Channel Encoding and Decoding [18 Lectures]:

Overview of Channel coding and Deep Learning (3L)

DNN for Channel coding and to Decoding Directly (5L)

DNNs for joint equalization and Channel Decoding, CNNs for Decoding (5L)

Decoding by Eliminating Correlated Channel Noise, BP-CNN Decoding (5L)

Textbook

1. Zhechen Zhu, Ashoke K. Nandi, Automatic Modulation Classification: Principles, Algorithms and Applications
2. Luo, F. L., (2020), *Machine Learning for Future Wireless Communications*, Wiley
3. He, R., and Ding Z., (2019), *Application of Machine Learning in Wireless Communications*, The Institution of Engineering and Technology

Self Learning Material

Machine Learning For Communications Emerging Technologies Initiative, IEEE
https://mlc.committees.comsoc.org/research-library/

Preparatory Course Material

Jagannatham, A. K., Principles of Communication II, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104098/

Title	**Delay Tolerant Networks**	Number	**EEL7XX**
Department	Electrical Engineering/ Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Elective
Prerequisite	Data Communication Networks, Data and Computer Communications		

Objectives

The Instructor will:

Expose students to theoretical and practical work and knowledge in the field of Delay-Tolerant Networks

Learning Outcomes

The students are expected to have the ability to:

1. Study the problems with networking in networks tolerant of huge delay and with problems in the connectivity.
2. Analysis of protocols and possible application used in DTNs (sensor networks, space communications, mobile ad-hoc networks)

Contents

Introduction for Delay-Tolerant Networking (DTN) [3 Lectures]

Networking in stress and high heterogeneous environments. Asynchronous message sending. Combination of store-and-forward message switching with physical data transmission/receiving. [5 Lectures]

Medium access control for delay-tolerant services. Quality of service; streaming control [4 Lectures]

Modeling of telecommunication traffic; modeling of delays and queues; modeling of delay-tolerant queues. [4 Lectures]

DTN protocol stack [3 Lectures]

Deterministic and probabilistic routing protocols [5 Lectures]

DTN Security issues [8 Lectures]: Attacks on DTN (3L), Solution (5L)

DTN application requirements, Concrete DTN implementations [11 Lectures]: inter-planetary communications (3L), submarine communications (2L), sensor networks (3L), mobile ad-hoc networks (3L)

Textbook

Vasilakos, A. V., Zhang, Y., and Spyropoulos, T., (2011), Delay Tolerant Networks: Protocols and Applications, CRC Press

Self Learning Material

Machine Learning For Communications Emerging Technologies Initiative, IEEE
https://mlc.committees.comsoc.org/research-library/

Preparatory Course Material

Title	**Hardware Aware Communications**	Number	**EEL7XX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech.	Type	Elective
Prerequisite	Pattern Recognition and Machine Learning, Data and Computer Communications, Intelligent Radio Networks		

Objectives
The Instructor will:
Concepts related to hardware aware communications

Learning Outcomes
The students are expected to have the ability to:
Perform hardware-algorithm co-design for communications.

Contents
Application aware communication for IoT devices [6 Lectures]
Joint Sampling, Communication, and Inference [6 Lectures]
Intelligent communication for heterogeneous hardware constraints [6 Lectures]
Transfer learning for different hardware constraints [6 Lectures]
Hardware-algorithm co-design [6 Lectures]
Full-Dulplex Radios: Self-Interference Cancellation [6 Lectures]
Hardware-aware communication protocols [6 Lectures]

Self Learning Material
Machine Learning For Communications Emerging Technologies Initiative, IEEE
https://mlc.committees.comsoc.org/research-library/

Preparatory Course Material

Nano and Flexible Electronics Specialization

Title	**Introduction To Spintronics**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite			

Objectives

The Instructor will:

Provide fundamental concepts on spintronics

Learning Outcomes

The students are expected to have the ability to:

1. Understand the operation of spin based devices
2. Apply the knowledge for the improvement of spin based devices

Contents

Introduction: The early history of spin, Quantum Mechanics of spin, Bohr Planetary Model and Space Quantization, Bloch sphere, Spin-orbit interaction, exchange interaction (5 Lectures)

Spin relaxation mechanism, spin relaxation in metals and semiconductors, spin Galvanic effect, spin dependent transport and tunneling (5 Lectures)

Spin Phenomena [6 Lectures]:

Spin Hall Effect, Galvanic Effect (2 Lectures), Spin Capacitor Effect, Spin Hanle Effect, Spin Seebeck Effect, Spin Peltier Effect (4 Lectures)

Spin Transfer Torque [8 Lectures]:

Introduction, Spin-transfer drive magnetic dynamics (4 Lectures), Current-driven switching of magnetization, Domain wall motion and scattering (4 Lectures)

Semiconductor Spintronics [9 Lectures]:

Quantum spin-polarized transport, Pure spin currents, Spin-orbit interaction in semiconductors (4 Lectures), Spectral problem of the Rashba Hamiltonian, Geometric spin phases, Diluted magnetic semiconductors (5 Lectures)

Spintronic Devices [9 Lectures]:

Spin diode and transistors, Datta-Das spin-FET, Spin-Valve, spin based bio-sensors (4 Lectures)

Qubits and introduction to quantum computing (5 Lectures)

Textbooks

S. Bandyopadhyay, M. Cahay, *Introduction to Spintronics.* CRC Press, 2nd edition, 2015.

Self Learning Material

1. S. Datta, *Electronic Transport in Mesoscopic Systems*. Cambridge University Press, Revised edition, 1997.

2. Žutić, I., Fabian, J. & Das Sarma, S. *Spintronics: fundamentals and applications*. Rev. Mod. Phys. 76, 323–410 (2004)

3. David J. Griffiths, *Introduction to Quantum Mechanics*, Pearson Education, 2nd edition, 2015.

Preparatory Course Material

Prof. A. Perumal, *Spintronics: Physics and Technology*, NPTEL Course Material, Department of Physics, Indian Institute of Technology Guwahati,

https://nptel.ac.in/courses/115103039/

Title	**Flexible and Printed Electronics**	Number	**EEL7330**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV, M.Tech., Ph.D	Type	Elective
Prerequisite	Understanding of Electronic Materials and Devices		

Objectives

The Instructor will:

1. Explain fundamentals of thin-film electronic materials and devices for flexible electronics.
2. Teach the concepts for heterogeneous integration of thin-film devices on flexible platforms.
3. Will give an overview of the different printing and coating techniques.

Learning Outcomes

The students are expected to have the ability to:

1. Identify the advantages, drawbacks, performances, complementarity and uniqueness of large area manufacturing vs. silicon technology
2. Integrate the operation principles, architectures and processing of main devices and systems fabricated for flexible electronics
3. Predict systems integration issues and propose methods for integration and encapsulation of printed devices and systems

Contents

Introduction to Flexible and Printed Electronics (2 Lectures):

Evolution of Flexible Electronics, review of cutting edge research on flexible, plastic, stretchable, conformable or printed electronics. Materials, components, and systems, applications for IoT

Materials, Processing, and Manufacturing (12 Lectures):

Various semiconductors, dielectric, and conducting materials, Organic semiconductors (4 L); From chemical bonds to bands, Charge injection and transport, Examples of printable functional materials , Thin-film Deposition and Processing Methods for Flexible Devices (4 L), Solution-based Patterning Processes; Ink-jet printing, gravure and other processes, surface energy effects, multilayer patterning (4 L)

Flexible Thin-Film Transistors and Circuits (14 Lectures):

Thin-Film Transistor; Device structure and performance, Electrical characteristics, parameter extraction, characterization methods for rigid and flexible devices, electrical stability, printed transistors (5 L); Organic/polymer, metal-oxide, electrolyte gated, Case studies, submicrometer OTFTs and gravure printed OTFTs (5 L), From transistors to circuits, circuits on flexible and non- silicon substrates, Contacts and Interfaces to Organic and Inorganic Electronic Devices, Schottky contacts, defects, carrier recombination, effect of applied mechanical strain (4 L)

Other Flexible Devices and System Integration (14 Lectures):

Organic Light Emitting Diodes, flexible OLED displays and lighting, smart wallpaper (5 L), Organic Solar Cells, sensors, flexible batteries, supercapacitors, logic, memory, RFID tags (5 L), Latest applications, Encapsulation, Roll to roll processes, Integration Issues, and Designs for Future (4 L)

Textbook

1. Nisato, G., Lupo, D., Ganz, S. (Editors) (2016), *Organic and Printed Electronics: Fundamentals and Applications*, 1st Edition, CRC Press
2. Caironi, M., Noh, Y-Y., (Editors) (2015), *Large Area and Flexible Electronics*, 2nd Edition, WILEY-VCH
3. Wong, W. S., and Salleo, A., (Editors) (2009) *Flexible electronics: Materials and Applications*, 1st Edition, Springer

Self Learning Material

Recent Papers form Flexible and Printed Electronics area, IEEE, IOP, AIP, RSC and others

Title	**Advanced Compact Modeling**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	2–0–0 [3]
Offered for	B.Tech.	Type	Specialization Core
Prerequisite	Physics and Modeling of the MOS Transistors		

Objectives

The Instructor will:

1. Provide understanding of industry standard compact modeling techniques
2. Introduce SPICE simulations

Learning Outcomes

The students are expected to have the ability to:

1. Identify best compact modeling approach for their problem
2. Develop own compact models and use them in circuit simulations

Contents

Introduction to TCAD Simulations, SPICE simulations and Compact Modeling (3 Lectures)

Resistor and Diode Modeling [7 Lectures]:

Semiconductor resistors, 2-terminal resistor model, 3-terminal resistor model (4 Lectures)

JUNCAP2 diode model, charge and capacitance models, diode breakdown model (3 Lectures)

Compact Modeling Techniques [7 Lectures]:

Charge based, threshold voltage based and surface potential-based modeling of MOS transistor, table look-up-based models (4 Lectures)

Developing analytical solutions, error margin. Accessing in-built compact models inside simulators (3 Lectures)

Advanced Multi-Gate Devices *[7 Lectures]:*

Introduction to FinFETs, Charge based modeling of FinFETs (4 Lectures)

Introduction to Gate-All-Around Transistors and modeling (3 Lectures)

Parameter Extraction and Benchmark Testing: Importance of parameter extraction and extraction procedure. Symmetry tests for DC and capacitances, harmonic balance test, slope-ratio tests, gm/Id test. (4 Lectures)

Textbooks

1. G. Gildenblat, *Compact Modeling: Principles, Techniques and Applications*. Springer, 2010.
2. W. Liu, *MOSFET Models for SPICE Simulation: Including BSIM3v3 and BSIM4*, Wiley, 2001

Self Learning Material

Research papers on semiconductor device modeling

Preparatory Course Material

K. Kundert, *Designer's Guide to SPICE and SPECTRE*, Springer, 1995

Title	**Quantum Nanoelectronics**	Number	
Department	Electrical Engineering	L-T-P [E]	3–0–0 [3]
Offered for	B.Tech. 4th Year	Type	Elective Course
Prerequisite	Semiconductor Devices		

Objectives

The Instructor will :

1. Each the fundamentals of quantum nanoelectronics
2. Explain the nano structures classifications and transport mechanism in quantum structures
3. Briefly teach the fabrication and characterization of Nanoelectronic Devices

Learning Outcomes

The students are expected to have the ability to:

1. Have a deeper understanding of Nanostructures
2. Understand the basic concepts of Nanoelectronic devices

Contents

Introduction and review of electronic technology (5 lectures):

Electronics to nanoelectronics, particles, waves and Schrodinger Equation, quantum wells, wires and dots, quantum description of metals, semiconductors, junction devices

Building blocks for nanoelectronic devices (15 lectures):

Fabrication and characterization methods for nanoelectronics (5 L); FET – size limits and alternative forms, devices based on electron tunneling, resonant tunnel diodes (5 L); Single electron transistors, molecular electronics, hybrid electronics (5 L)

Transport of charge in Nanostructures under Electric field (8 lectures):

Parallel transport, hot electrons, perpendicular transport (4 L), Quantum transport in nanostructures, Coulomb blockade (4 L)

Transport of charge in magnetic field (5 lectures):

Effect of magnetic field on a crystal. Aharonov-Bohm effect, the Shubnikov-de Hass effect, the quantum Hall effect.

Alternate Devices (9 lectures):

*Structure and properties of h*eterojunction devices (4 L), Heterostructure semiconductor laser, Quantum well laser, quantum dot LED, quantum dot laser, Quantum well optical modulator (5 L)

Textbook

1. Martinez-Duart J. M., Martin Palma R. J., Rueda F. A., (2006), *Nanotechnology for Microelectronics and optoelectronics*, Elsevier
2. Fahrner W. R., (2005), *Nanotechnology and Nanoelectronics*, Springer

Preparatory Course Material

Nanoelectronics: Devices and Materials, Centre for Nanoscience and Engineering, IISc Bangalore, NPTEL Course, https://nptel.ac.in/courses/117108047/

Title	**Non-Volatile Memory Technologies**	Number	
Department	Electrical Engineering	L-T-P [C]	2–0–0 [2]
Offered for	B.Tech.	Type	Compulsory /Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background knowledge of advanced non-volatile memory technologies.
2. Teach the students about emerging memory devices and applications.

Learning Outcomes

The students are expected to have the ability to:

1. Describe the structure and operation of non-volatile devices, and challenges associated with them
2. Explain the physics with new structures such RRAM devices
3. Understand the operation of new memory technologies and related circuits.

Contents

Memory Development for CMOS (8 Lectures):

Historical Progress in Data Storage Devices and Techniques for Computing and CMOS, Scaling of Memory and ITRS (4 L), Memory Types and Hierarchy, Static and Dynamic Memory Designs, NAND and NOR Flash Memory, Fabrication Techniques (4 L)

Emerging Non-Volatile Memory Technologies (20 Lectures):

Non-volatile memory technologies and their properties, Magnetoresistive Random Access Memory (MRAM), Phase change RAM (PCRAM), Ferroelectric RAM (FeRAM) (5 L), Resistive RAM (RRAM), Applications of RRAM, Fabrication and Process Considerations (5L); Memristers, Synapse, RRAM devices and Memristers for Neuromorphic Applications (5 L); Design implications of emerging non-volatile memory (NVM) technologies, in-memory computing (5 L)

Textbook

1. Hu, C. (2010), Modern Semiconductor Devices for Integrated Circuits, Prentice Hall.
2. Suri, M. (2020), Applications of Emerging Memory Technology, Springer.

Self Learning Material

Recent Papers on Emerging Memory Technologies

Title	**Semiconductor Optoelectronics**	Number	
Department	Electrical Engineering	L-T-P [E]	3–0–0 [3]
Offered for		Type	Elective Course
Prerequisite	Semiconductor Devices		

Objectives

The Instructor will :

1. Provide students an understanding of operation of semiconductor optoelectronic devices.
2. Teach students heterojunctions and quantum wells and their application to optoelectronic devices.
3. Teach students design, analysis, & modelling of semiconductor LEDs and lasers.
4. Teach students design of various types of photodetectors and optical fibers

Learning Outcomes

The students are expected to have the ability to:

1. Be familiarized with optoelectronics devices and understand the physical principle behind this.
2. Design single-mode junction lasers at different wavelengths to meets specs.
3. Design junction & avalanche photodiodes to meet specs
4. Incorporate heterostructures and quantum wells to improve device performance devices.

Contents

Compound Semiconductors [6 Lectures]:
Semiconductor optoelectronic materials, Structures (2L)
Fermi level and quasi Fermi levels, band gap modification(4L)
Semiconductor Photon Sources [4 Lectures]: Interaction of photons with electrons and holes in a semiconductor, Rates of emission and absorption, Luminescence
Quantum structures in semiconductors [4 Lectures]: Quantum wells, quantum dots, quantum wires.
Light Emitting diodes [5 Lectures]: materials, structure and device characteristics
Semiconductor Laser[9 Lectures]:
Dasic structure, theory and device characteristics, DFB, DBR (5L)
Quantum well and VCSE Lasers, Laser diode arrays(4L)
Semiconductor Photodetectors [6 Lectures]: Types of photodetectors: photoconductors and photodiodes, PIN diodes and Avalanche photodetectors and their characteristics
Solar cells [4 Lectures]: Basic principle, current voltage characteristics, Spectral response, Heterojunction and cascaded solar cells.
Optics [4 Lectures]: Integrated optics, Optical fibers and their characteristics, Fiber optic communication systems

Textbooks

1. Sze S. M., (2001), *Physics of Semiconductor Devices*, John Wiley & Sons.
2. Streetman B. G., Banerjee S. K., (2007), *Solid State Electronic Devices*, Pearson Education Asia.
3. Bhattacharya P., (1993), *Semiconductor Optoelectronics devices,* Pearson Education

Title	**Organic Optoelectronics**	Number	
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Compulsory /Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide fundamental understanding of the optical and electronic properties of organic materials and devices
2. Teach the students the basics of the emerging technological area of printed flexible optoelectronics

Learning Outcomes

The students are expected to have the ability to:

1. Demonstrate understanding of the various key classes of organic optoelectronics, their basic device structures as well as identify their fundamental advantages and disadvantages
2. Propose an appropriate characterization technique in order to characterize a specific property relating to the material and the targeted application
3. Apply the knowledge of an enabling technology meeting the needs of society, in the field of organic electronics and nanotechnology

Contents

Organic Molecules and Molecular Solids (5 Lectures): Electronic structure of atoms, Atomic and Molecular Orbitals, LCAO, Bonding and antibondig orbitals, Covalent Bond, Sigma and Pi Bonds, Energy Levels, Spectroscopic properties, Aggregates, Van der Waals Bonding, Hydrogen Bonding

Photophysics and Conduction (9 Lectures):

Excited states: Absorption and emission, Singlet and triplet states, Radiative and non-radiative transitions, Dimer, Eximers; Excitons: Wannier Exciton, Charge-transfer Exciton Frenkel Exciton, Exciton Diffusion, Excitonic Energy Transfer (5 L); Conduction in Organic Solids: Conductivity: carrier concentration versus mobility, Carrier generation, Hopping transport, Mobility measurements, Traps. (4 L)

Flat panel display technologies and Lasers (12 Lectures):

Physics of liquid-crystal displays; organic light-emitting diodes: materials, devices and applications (4 L); fundamentals of radiometry, Organic Light Emitting Transistors (4 L), Lasing Action in Organic Semiconductors: Lasing Process, Optically Pumped Organic Lasers, Electrical Pumping of Organic Lasers (4 L).

Photovoltaics and Photodetectors *(8 Lectures)*:

Photovoltaic Devices, Organic Heterojunction Photovoltaic Cells, Organic/Nanorod hybrid Photovoltaics (4 L), Gratzel Cells (Dye sensitized solar cells), Photodetector Devices (4 L)

Essential Fabrication Technology (8 Lectures): Film Formation Techniques: Spin coating, Langmuir-Blodget, Evaporation, Chemical Vapor Phase Deposition (4 L), Printing and coating techniques, Ink-Jet Printing, Self-Assembly, Introduction to modern xerography (4 L)

Textbook

Hu, W., (Editor), (2013), Organic Optoelectronics, 1st Edition, Wiley-VCH

Self Learning Material

Recent Papers on topics such as OLEDs, OLETs and OPVs

Smart Grid Specialization

Title	**Introduction to Smart Grid**	Number	**EE7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech/Ph.D.	Type	Compulsory
Prerequisite	Power Engineering (for B.Tech. students)		

Objectives

The Instructor will:

Provide concepts and topics that are relevant to smart grid technologies to facilitate exploring research opportunities

Learning Outcomes

The students are expected to have the ability to:

Understand the basic concepts of smart grid development and the critical technologies that underpin such development, their basic principles, physical constraints, and technological potentials

Contents

Smart Grid Basics: Evolution of Electric Power Grid and Smart Grid, Objectives, main features and challenges of smart grid (5 lectures)

Energy Resources: Centralized vs. distributed generation (1 lecture); renewable energy: solar, wind, hydropower, biomass, geothermal, ocean wave; benefit, costs, and policies of renewable energy (5 lectures); renewable sources integration – overcoming intermittence; storage systems technology (4 lectures)

Plug-in Electric Vehicle (PEV): History of EV; PEV challenges and potential solutions (1 lecture); EV and electric power grid; PEV charging infrastructure, challenges and solutions (4 lectures); PEV as an energy storage device and an energy source (V2G) (2 lectures)

Demand-side management: Load profile of the power grid; market pricing (3 lectures); peak shaving and valley filling; load forecasting (4 lectures); regulations and policies (3 lectures)

Monitoring and Protection: Wide-area monitoring system (WAMS), SCADA and PMU (4 lectures); advanced metering infrastructure (AMI); smart metering (3 lectures); communication infrastructure and technologies (3 lectures)

Textbook

1. Bollean,M.H.J., Hasan,F., (2011), *Integration of Distributed Generation in the Power Systems*, Willey-IEEE India Press
2. Ehsani,M., Gao,Y., Gay,S.E., Emadi,A., (2005), *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*, CRC Press
3. Bansal,R., (2019), *Power System Protection in Smart Grid Environment*, CRC Press

Self Learning Material

The Smart Grid: An Introduction,
http://www.oe.energy.gov/SmartGridIntroduction.htm, Department of Energy, 2008.

Title	**Renewable Energy Systems**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Compulsory
Prerequisite			

Objectives

The Instructor will:

Provide exposure to operation of various non-conventional energy sources, their characteristics, and their interface with grid

Learning Outcomes

The students are expected to have the ability to:

Design and develop standalone and grid connected renewable energy systems

Contents

Solar PV: Solar PV characteristics, cell, module, array, series parallel combination, partial shading, MPPT (3 lectures), grid synchronization using various converter topologies (3 lectures)

Solar Thermal: Principle of operation, thermal efficiency, concentrators-architecture, applications (4 lectures)

Wind Energy Systems: Principle of operation, types of wind turbines, Cp-λ characteristics, Betz limit, MPPT, onshore and offshore wind farms (4 lectures), types of wind generators-operation and control of various types of generators (6 lectures)

Hydro Power Generation: Hydro systems, hydro resources, types of hydro turbine, small, mini and micro hydro systems, pumped storage (6 lectures)

Fuel Cells: Types, principle of operation, V-I characteristics, applications (4 lectures)

Other Renewable Energy Sources: Introduction to geothermal, ocean, biomass energy generation (6 lectures)

Energy Storage Systems: Introduction to various mechanical, chemical, electro-chemical, and electrical storage systems and their applications (6 lectures)

Textbook

1. Bollean,M.H.J., Hasan,F., (2011), *Integration of Distributed Generation in the Power Systems*, Willey-IEEE India Press
2. Masters,G.M., (2004), *Renewable and Efficient Electric Power Systems*, John Wiley & Sons, Inc.
3. Bhadra,S.N., Kastha,D., Banerjee, S., (2005), *Wind Electrical Systems*, Oxford Univ. Press

Title	**Power Quality**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–0 [2]
Offered for	B.Tech./M.Tech/Ph.D.	Type	Compulsory
Prerequisite	Introduction to Electrical Engineering		

Objectives

The Instructor will provide knowledge of:

1. Various Power quality issues and their origin
2. Impact of various power quality problems on appliances
3. Various compensators/filters used for mitigating different PQ issues

Learning Outcomes

The students are expected to have ability to:

1. Identify the sources of various power quality problems.
2. Estimate the impact of various power quality problems on appliances.
3. Decide the compensators and filters to keep the power quality indices within the standards

Contents

Overview and definition of power quality (PQ): Sources of pollution and regulations (2 lectures), power quality problems, rapid voltage fluctuations voltage unbalance, voltage dips and voltage swells, short duration outages (4 lectures)

Definitions Voltage sag analysis and mitigation: Sag caused by motor starting, sag caused by utility fault clearing, sag mitigation, sag magnitude and duration calculations, RMS voltage, calculation in 1-phase systems (6 lectures)

Harmonics: Effects-within the power system, interference with communication harmonic measurements, harmonic elimination (4 lectures)

Harmonic distortion: Overview of power system harmonics, harmonic analysis, harmonic sources-the static converters, transformer magnetization and non-linearities, rotating machines, arc furnaces, fluorescent lighting (5 lectures), total harmonic distortion, rms and average value calculations, effects of harmonic distortion (3 lectures)

Monitoring power quality: Monitoring essentials, power quality measuring equipment, current industry trends (4 lectures)

Textbook

1. Kennedy,B.W., (2000), *Power Quality Primer*, McGrawHill.
2. Dugan,R.C., Mcgranaghan,M.F., Santoso,S., Beaty,H.W., (2002), *Electrical Power System Quality*, McGrawHill.
3. Bollen,M.H.J., (2007), *Understanding Power Quality Problems: Voltage Sag and Interruptions*, IEEE Press.

Title	**Power System Protection**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech.	Type	Elective
Prerequisite	Power System Analysis and Stability		

Objectives

The Instructor will provide knowledge of:

1. Various protection schemes and their applications in power industry
2. Relay coordination, instrument transformers
3. Numerical protection schemes based on signal processing techniques

Learning Outcomes

The students are expected to have the ability to:

1. Design/propose protection schemes for various power system components based on digital signal processing
2. Design relay coordination systems in distribution and transmission

Contents

Overview of Power System Protection: Architecture of protection system, evolution of relays, zones of protections, concept of primary and back-up protection (2 lectures)

Overcurrent Protection: Principles of fuse and overcurrent protection and application to feeder and motor protection, relay coordination in distribution system (6 lectures)

Distance Protection: Principles of distance relaying (2 lectures) and application to transmission system protection, relay coordination (5 lectures)

Differential Protection: Principles of differential protection (2 lectures) and application to transformer, bus bar and generator armature winding protection (5 lectures)

Introduction to Digital Relaying: Sampling, concept of moving window, signal conditioning, signal processing (4 lectures)

Instrument Transformer: Current and voltage transformers in power system protection (6 lectures)

Circuit breakers: Arc initiation and quenching, oil circuit breakers, air blast circuit breakers vacuum circuit breakers, SF6 circuit breakers (5 lectures), current chopping, reverse recovery voltage (3 lectures)

Lightning arresters: Principle of operation and types (2 lectures)

Textbook

1. Singh, L.P., (2017), *Digital Protection: Protective Relaying from Electromechanical to Microprocessor*, 2nd Edition, New Age International Publications
2. Ram,B., Vishwakarma,D.N., (2017), *Power System Protection and Switchgear*, 2nd Edition, Tata McGraw Hill Publications.
3. Phadke,A.G., Thorp,J.S., (2009), *Computer relaying for Power System*, 2nd Edition, John Wiley & Sons Ltd. Publications

Self Learning Material

Soman,S.A., *Power System Protection,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Bombay,
https://nptel.ac.in/courses/108/101/108101039/

Title	**Power System Dynamics and Control**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech/Ph.D.	Type	Elective
Prerequisite	Power System Analysis and Stability (for B.Tech student)		

Objectives

The Instructor will:

1. Provide exposure to dynamic behaviour of synchronous machines under small and large disturbances and the concept of voltage stability in a power system
2. Provide exposure to the mathematical methods of improving system stability

Learning Outcomes

The students are expected to have the ability to:

1. Design and implement techniques to control a power system
2. Design control techniques/stabilizers to improve the system stability

Contents

Introduction to stability problem: Rotor angle stability, voltage stability, mid-term and long-term stability, small signal stability, transient stability, oscillatory and non-oscillatory instability (2 lectures)

Modeling of synchronous machine: synchronous machine parameters, dq-axis modeling, voltage equations, per-unit modeling, equivalent circuit, dq-axis time constants, swing equations (4 lectures), synchronous machine representation in stability students, capability curve of an alternator (3 lectures)

Excitation systems: Elements, types, dynamic performance measures, control and protective functions (5 lectures), modeling of excitation systems (2 lectures)

Governor modeling and automatic generation control: Turbine, governor modeling, isochronous governor, speed-droop characteristics, automatic generation control (3 lectures)

Small signal stability analysis: Eigen properties, participation and sensitivity analysis (3 lectures), SMIB system, synchronizing and damping torque, K1-K6 model (5 lectures), PSS design and types (2 lectures)

Transient stability analysis: Equal area criteria, direct method of transient stability analysis (5 lectures)

Voltage stability issues: PV characteristics, voltage collapse phenomenon, prevention of voltage collapse (5 lectures)

Sub synchronous oscillations: Torsional oscillations in multi-mass turbine, interactions with nearby dc systems (3 lectures)

Textbook

1. Kundur,P., (1994), *Power System Stability and Control*, McGraw Hill
2. Machowski,J., Bialek,J., Bumby,J.R., (2008), *Power Systems Dynamics, Stability and Control*, 2nd Edition, John Wiley.

Self Learning Material

Kothari,M.L., *Power System Dynamics,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi,
https://nptel.ac.in/courses/108/102/108102080/

Title	**HVDC and FACTS**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech./Ph.D.	Type	Elective
Prerequisite	Power System Analysis and Stability, Power Electronics (for B.Tech students)		

Objectives

The Instructor will:

1. Present the need and operational aspects of HVDC transmission systems along with their associated converters and their control
2. Provide concepts of series and shunt compensation to enhance the performance of transmission lines and stability of Power System using FACTS devices

Learning Outcomes

The students are expected to have the ability to:

1. Develop converters and their control methods in HVDC transmission systems
2. Develop converter topologies and their control methods for FACTS devices

Contents

Introduction: Introduction of DC power transmission technology, comparison of AC and DC transmission, advantages, limitations and types of HVDC transmission systems (3 lectures)
LCC HVDC systems: Ignition angle, commutation overlap, relation between AC and DC quantities (4 lectures)
Control of HVDC systems: CIA, CC, CEA characteristics, current limits (3 lectures)
Harmonics and filters: AC and DC side harmonics (3 lectures)
Interaction with AC system: Effective Short Circuit Ratio, dynamic overvoltage, voltage stability, harmonic resonance (2 lectures)
Introduction to VSC HVDC systems: Introduction to VSC HVDC systems, voltage analysis, active and reactive power flow, control of VSC HVDC systems (3 lectures)
FACTS devices: Objectives of compensation, types of compensation (2 lectures)
Shunt compensators: TCR, TSR, TSC, SVC and STATCOM - principle of operation, modeling, and control (6 lectures)
Series compensation: SSSC, TSSC, TCSC, and TCSR - principle of operation, modeling, and control (6 lectures)
Voltage and phase angle regulators: Thyristor controlled voltage and phase angle regulators - principle of operation, modeling, and control (4 lectures)
Power flow controllers – UPFC and IPFC - principle of operation, modeling, and control (6 lectures)

Textbook

1. Padiyar,K.R., (2017), *HVDC Power Transmission Systems*, 3rd Edition, New Age Publishers
2. Hingorani,L.G., Gyugyi,L., (2000), *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*, IEEE Press

Self Learning Material

1. Singh,S.N., *High Voltage DC Transmission,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108/104/108104013/
2. Bhattacharya,A., *Facts Devices,* NPTEL Course Material, Department of Electrical and Electronics Engineering, IIT Roorkee, https://nptel.ac.in/courses/108/107/108107114/

Title	**Power System Restructuring**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech./Ph.D.	Type	Elective
Prerequisite	Power Engineering (for BTech students)		

Objectives

The Instructor will:

Provide understanding of economics of a restructured power system

Learning Outcomes

The students are expected to have the ability to:

Model markets, calculate and analyze price associated with power generation and transmission in a restructured power system

Contents

Introduction: Reasons and objectives for restructuring of power industry - Indian and global scenario, restructuring process, entities involved, market place mechanisms (4 lectures)

Fundamentals of Economics: Introduction, consumer and suppliers behavior, market equilibrium, costs of production, competitive market (5 lectures)

Market Models: Introduction, models based on contractual agreement, comparisons of market models, electricity vs. other commodities (4 lectures)

Transmission Congestion Management: Introduction, classification of congestion management methods, ATC, non-market methods, nodal pricing, inter-zonal intra-zonal congestion management, capacity alleviation method (6 lectures)

Locational Marginal Prices: Fundamentals, LMP formulation implementation, LMP using AC and DC OPF (4 lectures)

Ancillary Service Management: Type, services related to load-generation balancing, voltage and reactive power, black start capability service, co-optimization of energy and reserve services (4 lectures)

Pricing of transmission network usage and loss allocation: Principles and methods of transmission pricing, classification of transmission pricing methods, database issues in transmission pricing, loss allocation methods, comparison (5 lectures)

Market power and generators bidding: Attributes of a perfectly competitive market, the firm's supply decision under perfect competition, imperfect competition, market power, financial markets, introduction to optimal bidding by a generator company, optimal bidding methods (6 lectures)

Global and Indian energy market evolution: Global markets - ERCOT, PJM, Nordic power markets, need of standard market design, Indian market framework, reform initiatives, ABT, electricity acts (4 lectures)

Textbook

1. Kirschen,D., Strbac,G., (2004), *Fundamentals of Power System economics*, John Wiley & Sons Ltd
2. Hunt,S., (2002), *Making competition work in electricity*, John Wiley & Sons, Inc.,
3. Lai,L.L., (2001), *Power System Restructuring and Deregulation: Trading, Performance and Information Technology*, John Wiley & Sons Ltd

Self Learning Material

1. Abhyankar,A.R., Khaparde,S.A., *Restructured Power Systems,* NPTEL Course Material, https://nptel.ac.in/courses/108/101/108101005/

Title	**Power Quality Mitigation Techniques**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech./Ph.D.	Type	Elective
Prerequisite	Power Electronics, Power Quality (for B.Tech students), Power Quality (for M.Tech. students)		

Objectives

The Instructor will:

Provide an understanding of various techniques and components used to improve the power quality in distribution networks

Learning Outcomes

The students are expected to have the ability to:

Design topologies and control methods to mitigate power quality disturbances using active and passive filters

Contents

Introduction: Representation of harmonics, waveform, active, reactive and harmonic power, THD, distortion power, power factor (4 lectures)

Power components in three-phase circuits: $\alpha\beta 0$coordinates, instantaneous active and reactive power in three-phase balanced circuits, three-phase unbalanced circuit analysis using symmetrical components, power calculation in unbalanced and non-sinusoidal three phase systems (6 lectures)

Fundamentals of load compensation: Power factor improvement, voltage regulation (3 lectures), phase balancing using symmetrical components (5 lectures)

Theory of shunt compensation: State space modeling of compensator, switching control (3 lectures), reactive power theory, theory of instantaneous symmetrical components (5 lectures)

Theory of series compensation: Principle of operation and control of dynamic voltage restorer (6 lectures)

Unified power quality conditioner: Principle of operation of UPQC (4 lectures)

Harmonics suppression with passive filters: Types of filters and their design (6 lectures)

Textbook

1. Ghosh,A., Ledwich,G., (2002), *Power Quality Enhancement Using Custom Power Devices*, Springer Science+Business Media
2. Sankaran,C., (2002), *Power Quality*, CRC Press
3. Akagi,H., Watanabe,E.H., Aredes,M., (2017), *Instantaneous Power Theory and Applications to Power Conditioning*, Wiley-IEEE Press

Self Learning Material

1. Kumar,M., *Power Quality in Power Distribution Systems,* NPTEL Course Material, Department of Electrical Engineering, IIT Madras, https://nptel.ac.in/courses/108/106/108106025/
2. Bhattacharya,A., *Power Quality Improvement Technique,* NPTEL Course Material, Department of Electrical and Electronics Engineering, IIT Roorkee, https://nptel.ac.in/courses/108/107/108107157/

Title	**Plugin Electric Vehicles**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–2 [4]
Offered for	B.Tech./M.Tech./Ph.D.	Type	Elective
Prerequisite	Power Electronics, Introduction to Smart Grid (for B.Tech students), Introduction to Smart Grid (for M.Tech students)		

Objectives

The Instructor will:

Provide understanding of various technologies of plugin electric vehicle and hybrid electric vehicle and their role in smart grid operation

Learning Outcomes

The students are expected to have the ability to:

1. Design powertrain circuit topology and appropriate control scheme for electric vehicle
2. Understand and design EV charging infrastructure

Contents

Introduction to EV: Recent development trends, types of electric vehicles (2 lectures)
Powertrain: Concepts of powertrain sizing in EV and PHEV, starting, braking (6 lectures)
Storage systems: Battery types, parameters, battery modeling, battery management (5 lectures)
Charging Infrastructure: Domestic charging infrastructure, public charging infrastructure, normal charging station, occasional charging station, fast charging station, battery swapping station (5 lectures), types of charging: constant voltage, constant current, pulse charging, inductive, conductive charging (3 lectures)
Vehicle-to-X systems: Vehicle-to-grid, vehicle-to-home (5 lectures), vehicle-to-building, vehicle-to-vehicle (3 lectures)
Hybrid Electric Vehicle: Configuration of HEV (series, parallel, series-parallel & complex), power flow control in HEV configurations, control (6 lectures)
Vehicle Communication: Introduction to in-vehicle communications and controller area network (4 lectures)
PEV integration: Impact on transmission and distribution network (3 lectures)

Laboratory: Experiments related to the following topics will be conducted under laboratory component:
SoC estimation, control of electric vehicle drives, regenerative braking, powertrain and vehicle dynamics, EV chargers and their control, vehicle-to-grid technology, vehicle-to-vehicle technology, EV charging from solar PV, performance of aggregator, Use of simulation tools (MATLAB, SIEMENS EV related softwares) to simulate different subsystems of EV and different scenarios.

Textbook

1. Husain,I., (2011), *Electric and Hybrid Vehicles Design Fundamentals*, 2nd Edition, CRC Press
2. Ehsani,M., Gao,Y., Emadi,A., (2011), *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles Fundamentals, Theory and Design*, 2nd Edition, CRC Press
3. Larminie,J., Lowry,J., (2003), *Electric Vehicle Technology Explained*, Wiley

Self Learning Material

1. Jain,A.K., *Electric Vehicles - Part 1,* NPTEL Course Material, Department of Electrical Engineering, IIT Delhi, https://nptel.ac.in/courses/108/102/108102121/
2. Kumar,P., Majhi,S., *Introduction to Hybrid and Electric Vehicles,* NPTEL Course Material, Department of Electronics and Communication Engineering, IIT Guwahati, https://nptel.ac.in/courses/108/103/108103009/

Title	**Power System Reliability and Security**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech./Ph.D.	Type	Elective
Prerequisite	Power System Operation and Control (for B.Tech students)		

Objectives

The Instructor will:

Provide in depth understanding of reliability and security aspects of generation, transmission, and distribution systems

Learning Outcomes

The students are expected to have the ability to:

Develop methods to enhance the reliability of supply and security of power system components

Contents

*Introduction:*Concept of power system reliability and security. methods of assessment, cost, probabilistic reliability criteria (4 lectures)

*Generating capacity reliability:*Probability methods- generation model, loss of load indices, loss of energy indices (6 lectures), frequency and duration method- generation model, system risk indices (4 lectures)

*Interconnected systems:*Evaluation techniques for multi-interconnected systems, factors affecting emergency assistance, frequency and duration method (6 lectures)

*Operating reserve:*Various methods of estimation, security function approach, response risk (4 lectures)

*Composite generation and transmission systems:*Network configurations, state selection, system and load point indices, data requirements (5 lectures)

Distribution system reliability: Networks configurations, evaluation techniques (5 lectures), indices and factors affecting reliability (3 lectures)

*Power system security:*Security analysis, security assessment, contingency analysis, algorithms to determine system security, security assessment based on performance index (5 lectures)

Textbook

1. Billinton,R., Allan,R.N., (1986), *Reliability Evaluation of Power Systems*, 2nd Edition, Springer US
2. Billinton,R., Ringlee,R.J., Wood,A.J., (1973), *Power-System Reliability Calculations*, MIT Press
3. Singh,C., Jirutitijaroen,P., Mitra,J., (2018), *Electric Power Grid Reliability Evaluation: Models and Methods*, Wiley-IEEE Press

Title	**Selected Topics in Distributed Generation**	Number	**EE7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./M.Tech./Ph.D.	Type	Elective
Prerequisite	Power Electronics, Renewable Energy Systems (for B.Tech students)		

Objectives

The Instructor will:

1. Provide salient concepts of DG operation and control in both grid connected and autonomous modes
2. Provide exposure to the challenges related to stability, grid integration, and ancillary services in distributed generation

Learning Outcomes

The students are expected to have the ability to:

1. Develop control schemes for distributed generators to operate in grid connected and autonomous mode
2. Understand various challenges and propose solutions related to stability, grid integration and ancillary services in distributed generation

Contents

Distributed generation: Introduction, DG types, concept of inertia and frequency response, flexibility issues, ramping issues (3 lectures)

Control of distributed generation: Typical distributed energy sources (1 lecture), their modelling (5 lectures) and control(4 lectures)

Microgrids: Concept of microgrid, microgrid benefits, typical structures and configurations of various microgrids (3 lectures), control of converters in DC and AC microgrids (4 lectures), active and reactive power control, voltage and frequency control of inverter-based sources (3 lectures), virtual synchronous generators (2 lectures)

Stability: Stability issues with weak grid integration and in microgrid operation (4 lectures)

Other challenges in grid integration: Power quality requirements, DG support under abnormal grid conditions (3 lectures), issues related to islanding and reverse power flow, network congestion (5 lectures), and protection (2 lectures)

Ancillary services: Ancillary services with DGs, control for ancillary services, virtual power plants (3 lectures)

Textbook

1. Bollean,M.H.J., Hasan,F., (2011), *Integration of Distributed Generation in the Power Systems*, Willey-IEEE India Press
2. Masters,G.M., (2004), *Renewable and Efficient Electric Power Systems*, John Wiley & Sons, Inc.
3. Bevrani,H., Francois,B., Ise,T., (2017), *Microgrid Dynamics and Control*, John Wiley & Sons, Inc.

VLSI Systems

Course Title	**Hardware Design for Artificial Intelligence**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech, M. Tech., Ph.D.	Type	Core
Pre-requisite	Artificial Intelligence, Digital and Analog Design.		

Objectives

The Instructor will:

1. Enable students to learn the concepts of Hardware Design for Artificial Intelligence.
2. Provide exposure to the students about architectures and hardware co-design for AI.

Learning Outcomes

Students are expected to have the ability to:

1. Apply fundamental principles of ANN and DNN to hardware architectures.
2. Implement the basic designs for computing hardware for AI.

Contents:

Hardware Design for Artificial-Intelligence: Basics of Artificial Intelligence, Moore's law in context of AI, Need of fast computational resources, Hardware for training, Architectural Challenges for Training, Memory Challenges, Floating point accuracy. (4 Lectures)

Modern AI Hardware: CPUs, GPUs, FPGAs, Specialized accelerators, CPU vs. GPU: Speed, Power and Bandwidth. (5 Lectures)

AI Accelerators and Processors: DNN Accelerators and Architectures, Data reuse, Low-cost spatial architectures, Energy efficient dataflow, Datapath Taxonomy, Synchronization for parallel processing.(5 Lectures)

Computing in AI Hardware: Highly-Parallel Compute Paradigms, High-performance matrix multipliers: Systolic arrays; Reinforcement Learning for Hardware Design.(5 Lectures)

Performance Parameters: Implementation of Deep Learning Kernels; Evaluating Performance, Energy efficiency, Parallelism, Locality,Memory hierarchy, Roofline model: Multicore Architectures. (5 Lectures)

Hardware Optimization for AI: Bitwidth optimization, Nonlinear Quantization, Binary Nets, Log-Domain Computation. (5 Lectures)

Compact Network Architectures: Key Metrics for Embedded DNN, Sparse-Matrix Vector DSP, Compact Network Architectures (5 Lectures)

*Industry Standards and State-of-the Art***:** Study of state-of-the art accelerators such as Eyeriss(MIT), Intel Xeon, Intel Neural Compute Stick.(5 Lectures)

Other accelerators from Microsoft and IBM.(3 Lectures)

Text References

Sze,V. et al., "Efficient Processing of Deep Neural Networks: A Tutorial and Survey," *Proceedings of the IEEE,* vol. 105, no. 12, pp. 2295-2329, Dec. 2017.

Preparatory course material

1. Chen,Y.-H. et al., "Eyeriss: An Energy-Efficient Reconfigurable Accelerator for Deep Convolutional Neural Networks, "*IEEE International Conference on Solid-State Circuits (ISSCC),* pp. 262-264, February 2016.
2. *https://www.eecs.mit.edu/academics-admissions/subject-updates-fall-2017/6s0826888*
3. https://cs217.stanford.edu/
4. https://towardsdatascience.com/neural-network-architectures-156e5bad51ba

Additional Reading

Zhang,Q.J., Gupta,K.C., *Neural Networks for RF and Microwave Design*. Artech House Publishers, Boston, MA, USA, 2000.

Course Title	**VLSI Testing**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–0 [2]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Compulsory
Pre-requisite	High-level Synthesis, VLSI Design		

Objectives

The Instructor will:

1. Enable students to learn the concepts of testing and verification techniques used for VLSI integrated circuits.
2. Provide exposure to the students about complexity of VLSI testing in high-density VLSI chips in present scenario.

Learning Outcomes

Students are expected to have the ability to:

1. Apply principles of VLSI testing and verification for digital designs.
2. Implement the test patterns and circuitry for reasonably advanced logic circuits.

Contents

Basics of VLSI Testing: Introduction to Digital VLSI Design flow; VLSI Testing needs and challenges; Review of High-Level Synthesis, Scheduling, Allocation and Binding; Basics of VLSI testing, Flow of testing and verification; VLSI Testing Process, Equipment and Economics. (6 Lectures)

Fault Modeling: Faults and fault models, fault detection and redundancy, Yield and Fault Equivalence, Fault location, Fault dominance, Fault Simulation. (6 Lectures)

Automatic test pattern generation: Automatic test pattern generation (ATPG), Combinational ATPG, Sequential ATPG. (4 Lectures)

Design-for-testability: Design-for-testability (DFT), Testability Measures, Scan design, Test interface and boundary scan, JTAG, Delay fault testing. (5 Lectures)

BIST: Built in Self Test (BIST) for testing of logic and memories, Test automation. (3 Lectures)

New trends in Testing, Testing challenges for SoCs. (4 Lectures)

Text Books

1. M. Bushnell and V. D. Agrawal, *Essentials of Electronic Testing for Digital, Memory and Mixed Signal VLSI Circuits*. Springer, 2005.
2. T. Kropf, *Introduction to Formal Hardware Verification*. Springer Verlag, 2000.
3. N. H. E. Weste, D. Harris and A. Banerjee, *CMOS VLSI Design: A Circuits and Systems Perspective*. Pearson, 3rd edition, 2006.

Preparatory course material

1. M. Abramovici, M. Breuer and A. Friedman, *Digital System Testing and Testable Design*. IEEE Press, 1994.
2. NPTEL Course: VLSI Design Verification and Test. https://nptel.ac.in/courses/106103016/

Course Title	**Formal Verification**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–0 [2]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Compulsory
Pre-requisite	High-level Synthesis, VLSI Design		

Objectives

The Instructor will:

1. Enable students to learn the concepts of verification techniques used for VLSI integrated circuits.
2. Provide exposure to the students about complexity of verification in the high-density VLSI chips in present scenario.

Learning Outcomes

Students are expected to have the ability to:

1. Apply principles of formal verification for digital designs in VLSI systems.
2. Implement the programs for reasonably advanced logic circuits.

Contents

Introduction: Introduction to Digital VLSI Design flow; Needs and challenges of VLSI systems; Review of High-Level Synthesis; Basics of VLSI testing and verification, Flow of testing and verification. (4 Lectures)
Verification: Introduction- Functional verification, Timing verification, Formal verification. (4 Lectures)
Basics of equivalence checking and model checking, Hardware emulation. (2 Lectures)
Various Techniques of Verification: Design verification using simulation, analytical and formal techniques. (3 Lectures)
Formal equivalence checking, Finite automata and temporal logic, Symbolic trajectory evaluation, term rewriting, Verifying clock domain crossings. (5 Lectures)
Testbenches: Analog/mixed-signal verification, Assertion Based Verification. (3 Lectures)
System Verilog assertions, Verification testbenches, Use of verification algorithms. (4 Lectures)
SoC and CPU verification challenges, New directions in verification. (3 Lectures)

Text Books

1. M. Bushnell and V. D. Agrawal, *Essentials of Electronic Testing for Digital, Memory and Mixed Signal VLSI Circuits*. Springer, 2005.
2. T. Kropf, *Introduction to Formal Hardware Verification*. Springer Verlag, 2000.
3. N. H. E. Weste, D. Harris and A. Banerjee, *CMOS VLSI Design: A Circuits and Systems Perspective*. Pearson, 3rd edition, 2006.

Preparatory course material

1. Li.L.; Thornton,M., *Digital System Verification: A Combined Formal Methods and Simulation Framework*. Morgan & Claypool, 2010.
2. McFarland,M.,C., "Formal Verification of Sequential Hardware: A Tutorial", *IEEE Tran. on Computer-Aided Design of Integrated Circuits and Systems*, vol. 12, no. 5 , May 1993.
3. NPTEL Course: VLSI Design Verification and Test. https://nptel.ac.in/courses/106103016/

Course Title	**Advanced VLSI Design and Lab**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–2 [3]
Offered for	B.Tech, M. Tech., Ph.D.	Type	Compulsory
Pre-requisite	Basic VLSI Design		

Objectives

The Instructor will:

1. Enable students to learn the concepts of more advanced topics in VLSI Design to have an overview of VLSI subsystems.
2. Provide exposure to the students about system level issues and trade-offs in chip designs.

Learning Outcomes

Students are expected to have the ability to:

1. Design digital circuits for high-speed, low-power applications.
2. Implement VLSI subsystem designs using memory and arithmetic units.

Contents:

Introduction: Economics of VLSI systems, Review of CMOS logic circuits; impact of fabrication issues on design, ASIC design flow: logic synthesis, placement and routing. (4 Lectures)

High-speed Logic Circuits: High-speed switching circuits; Advanced clocking strategies and clock distribution; Logical effort, high-speed digital logic design using logical effort, performance optimization between speed and power. (6 Lectures)

Low-Power Design Technique: Deep submicron design issues; Leakage components, estimation and leakage tolerant design techniques, Subthreshold, Gate, Junction tunneling, GIDL, Diode leakage etc.; Scalability of leakage tolerant design techniques; Low-voltage designs including digital subthreshold operations, trade-off between high-speed and low-power designs. (6 Lectures)

Arithmetic and Memory Architectures: Arithmetic building blocks for ALU; Adders, Multipliers, Shifter, Barrel Shifter; Introduction to Memories; High performance memory and array structures. (6 Lectures)

Interconnect-aware Designs: Impact of scaling and interconnects, signal integrity, buffer insertion and inductive peaking, Low swing and Current mode signaling, Capacitively coupled interconnects. (6 Lectures)

Lab experiments: It will include designing and optimization of high-speed circuits using logical effort, Low-power circuits in subthreshold conduction, Memory architectures such as 6T SRAM cell, etc., fast adders and multipliers, interconnect aware designs.

Text Books

1. K. Roy and S. Prasad, *Low Voltage, Low Power VLSI Subsystems*.McGraw Hill Education, 1st edition, 2017.
2. I. Sutherland, R. F. Sproull and D. Harris, *Logical Effort: Designing Fast CMOS Circuits.* Morgan Kaufmann, 1st edition, 1999.
3. J. Rabaey, A. Chandrakasan and B. Nikolic, *Digital Integrated Circuits: A Design Perspective*, Prentice Hall, 2nd edition, 2009.

Self-Learning Material

Chandorkar,A.N. et al., Advanced VLSI Design, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Bombay,
https://nptel.ac.in/courses/117101004/

Preparatory course material

Y. Taur and T. Ning, Fundamentals of Modern VLSI Devices. Cambridge University Press, 2nd edition, 2016.

Title	**VLSI Broadband Communication Circuits**	Number	**EEL7XXX**
Department	Electrical Engineering	L-T-P	3–0–0 [3]
Offered for	B. Tech., M.Tech. , Ph.D.	Type	Elective
Prerequisite	Analog circuits, Basics of transmission lines, fundamentals of continuous time and discrete time signals and systems		

Objectives

The Instructor will:

1. Provide the basic understanding of signal degradation linked to broadband circuits.
2. Develop the ability to design and implement the integrated circuits for broadband communication.

Learning Outcomes

The students are expected to have the ability to:

1. Design broadband amplifiers, equalizers, data recovery circuits.

Contents

Digital signal transmission: Introduction to broadband digital communication, Channel characteristics-intersymbol interference, eye diagrams [3 lectures]
Digital communication over wired links, Mesochronous and Plesiochronous links [3 lectures]

Synchronization: Phase detectors for periodic signals and random data: Type I PLL [4 lectures]
Type II PLL [3 lectures]

Clock and data recovery circuits: Analog and digital implementations of CDRs [4 lectures],
Design implementation of PLL [3 lectures]

SerDes: Drivers and receivers for low frequencies [3lectures]
Serializer and Deserializer architectures and circuits [5 Lectures]

Equalization: Need of Linear and non-linear equalizers; LMS adaptation [2 lectures]
Equalizer design and related issues including noise and crosstalk [5 lectures]

Design challenges: Integrated circuit implementation issues of broadband amplifiers for transmission and reception [4 lectures]
Feedforward and decision feedback equalization [3 lectures]

Textbooks

1. Y. Tsividis, (2012),Mixed Analog Digital VLSI Devices and Technology (An introduction), World Scientific, New Jersey
2. K. R. Laker and W.M.C. Sansen, (1994), Design of Analog Integrated Circuits and Systems, McGraw-Hill
3. BehzadRazavi, (1996), Monolithic Phase Locked Loops and Clock Recovery Circuits-Theory and Design, John Wiley & Sons,

Preparatory course material

1. BehzadRazavi, (2015), Design of Integrated Circuits for Optical Communications,John Wiley & Sons.
2. David Johns and Ken Martin, (2013), Analog Integrated Circuit Design, John Wiley & Sons.

Artificial Intelligence of Things (AIoT) Specialization

Visual Computing Specialization

Title	**Image Synthesis**	Number	EE/CSE 7XXX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite	Computer Graphics, Digital Image Processing & Probability, Statistics, and Stochastic Processes		

Objectives

The Instructor will introduce students to fundamentals of realistic image synthesis.

Learning Outcomes

The students are expected to have the ability to synthesize realistic looking images for animations, simulation, gaming, etc.

Contents

The Goals of Rendering, Ray Tracing I: Basic Algorithm, Ray-Surface Intersection [4 Lectures]
Ray Tracing II: Acceleration Techniques [4 Lectures]

The Light Field, Lights and Lighting, Illumination, Camera and Film [4 Lectures]
Sampling and Reconstruction, Aliasing and Antialiasing, Statistical Sampling [4 Lectures]

Reflection Models: BRDFs, Ideal Specular and Diffuse [2 Lectures]
Reflection Models II: Glossy, Texture, the Rendering Equation [4 Lectures]
Materials and BRDFs, Mapping techniques, Exotic materials [4 Lectures]

Monte Carlo Methods: Probability, Sampling and Variance Reduction [3 Lectures]
Sampling Paths, Irradiance Caching and Photon Maps [5 Lectures]
Radiosity: Form Factors, Solvers [4 Lectures]
Meshing and Hierarchical Techniques [4 Lectures]

Textbooks

1. Akenine-Möller, T., Haines, E., & Hoffman, N. (2019). Real-time rendering. Crc Press.
2. Hughes, J. F., Van Dam, A., Foley, J. D., McGuire, M., Feiner, S. K., & Sklar, D. F. (2014). Computer graphics: principles and practice. Pearson Education.
3. Cohen, M. F., & Wallace, J. R. (2012). Radiosity and realistic image synthesis. Elsevier.

Self Learning Material

1. Prof. Pat Hanrahan, Computer Graphics: Image Synthesis Techniques, Stanford University: https://graphics.stanford.edu/courses/cs348b-00/
2. Prof. Ravi Raviramamoorthi, Computer Graphics, University of California, San Diego, https://www.youtube.com/user/raviramamoorthi/videos

Title	**Animation**	Number	EE/CSE 7XXX
Department	Electrical Engineering, CSE	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite	Computer Graphics		

Objectives

The Instructor will introduce students to fundamentals of animation and simulation.

Learning Outcomes

The students are expected to have the ability to use the animation techniques for physics based real time systems.

Contents

Core mathematics and methods for computer animation and motion simulation. [3 Lectures]
Traditional animation techniques. [3 Lectures]

Physics-based simulation methods for modeling shape and motion:
Particle systems, constraints, rigid bodies, [4 Lectures]
Deformable models, collisions and contact [4 Lectures]
Fluids, and fracture. [4 Lectures]
Animating natural phenomena. [4 Lectures]

Methods for animating virtual characters and crowds [4 Lectures]
Data-driven animation methods, realism and perception [4 Lectures]
Animation systems, motion control [4 Lectures]
Real-time and interactive methods [3 Lectures]
Multi-sensory feedback. [3 Lectures]

Textbooks

1. Hughes, J. F., Van Dam, A., Foley, J. D., McGuire, M., Feiner, S. K., & Sklar, D. F. (2014). Computer graphics: principles and practice. Pearson Education.
2. Parent, R. (2012). Computer animation: algorithms and techniques. Newnes.
3. Marschner, S., & Shirley, P. (2015). Fundamentals of computer graphics. CRC Press.

Self Learning Material

Prof. Doug James, Computer Graphics: Animation and Simulation, Stanford University, https://graphics.stanford.edu/courses/cs348b-00/

Title	**Computational Photography**	Number	EE/CSE 7XXX
Department	EE, CSE	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite	Basics of Image Processing		

Objectives

The Instructor will introduce students to the computational photography fundamentals.

Learning Outcomes

The students are expected to have the ability to design efficient algorithms for problems such as motion deblurring, compositing, warping and use computational cameras for intelligent sensing.

Contents

Modern optics and lenses;Radiometry and Photometry [3 lectures]
Camera models, aperture, shutter and energy calculations motion and defocus blur [2 Lectures]
Epsilon Photography, Single-shot Multi-domain Camera. [4 Lectures]
Computational Illumination: dual photography, relighting [4 Lectures]
Retrographic Sensing for the Measurement of Surface Texture and Shape. [5 Lectures]
Lightfields, Cameras for human-computer interaction, [3 Lectures]
Wavelengths and colors, Hyperspectral Imaging Techniques [3 Lectures]
Thermal cameras, high-speed [2 Lectures]
3D range-sensing cameras and camera arrays. [4 Lectures]
Removing camera shake and motion blur, Coded Aperture [4 Lectures]
Color manipulation, Image compositing [3 Lectures]
Panoramas, Warping and morphing, Motion Magnification. [5 Lectures]

Textbooks

1. Computer Vision: Algorithms and Applications, by Richard Szeliski.
2. Multiple View Geometry in Computer Vision, by Richard Hartley and Andrew Zisserman.
3. Reinhard, E., Heidrich, W., Debevec, P., Pattanaik, S., Ward, G., & Myszkowski, K. (2010). High dynamic range imaging: acquisition, display, and image-based lighting. Morgan Kaufmann.

Self Learning Material

1. Prof. Ramesh Raskar, Computational Camera and Photography, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/media-arts-and-sciences/mas-531-computational-camera-and-photography-fall-2009/index.htm
2. Prof.Ioannis (Yannis) Gkioulekas, Computational Photography, Carnegie Mellon University: http://graphics.cs.cmu.edu/courses/15-463/

Title	**Visual Perception**	Number	EEL7XXX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite			

Objectives
The Instructor will introduce students to the fundamentals for Visual Perception.

Learning Outcomes
The students are expected to have the ability of applying visual perception concepts to advance technologies of AR/VR, rendering, visualization, and and human computer interaction.

Contents
Introduction: Optical Information, Visual System [3 Lectures]
Perceiving Objects and Color [3 Lectures]
Visual System: Spatial Vision Perceiving Objects, Color[4 Lectures]
Depth and Movements [4 Lectures]
Spatial Vision: Perceiving Depth and Size, Perceiving Movement [5 Lectures]
Perceiving Scenes [3 Lectures]
Perception Functions and Categories [5 Lectures]
Visual Attention [5 Lectures]
Visual Memory [2 Lectures]
Applications in Image Synthesis, AR/VR [4 Lectures]
Rendering, and Visualization [4 Lectures]

Textbooks
1. Goldstein, E. Bruce, and James Brockmole (2016). Sensation and perception. Cengage Learning.
2. Gordon, Ian E. Theories of visual perception (2004). Psychology press.
3. DeValois, Russell L., and Karen K. DeValois (1990). Spatial vision. Oxford university press.
4. Davies, E. R. (2004). Machine vision: theory, algorithms, practicalities. Elsevier.

Self Learning Material
Prof. Aditi Majumder, Visual Perception, University of California, Irvine,
https://www.ics.uci.edu/~majumder/vispercep/vispercep.htm

Title	**Image and Video Forensics**	Number	**EE7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite	Digital Image Processing & Probability, Statistics, and Stochastic Processes		

Objectives

The Instructor will :

1. Introduce the framework of Image and Video Forensics.
2. Discuss the various techniques for forgery detection in Images and Videos.

Learning Outcomes

The students are expected to have the ability to:

Design an appropriate method for forgery detection based on available information.

Contents

Image and Video Forgeries [3 Lectures]: Image formation, Types of Image and Video Forgery, Splicing, Copy-Move, Retouching, Deep Fakes.

Camera Finger-printing [7 Lectures]:

Camera Response Function, Noise [3 Lectures]

Camera Signature,Camera Parameters based detection. [4 Lectures]

Coding based Techniques [7 Lectures]:

Image and Video Coding, Coding Priors, Compression Signatures [4 Lectures]

Frame based analysis (insertion, deletion, replication, shuffling), Audio Analysis. [3 Lectures]

Scene/Feature based Techniques [17 Lectures]:

Gradients, Motion, Motion Blur, Defocus Blur, Depth, Noise [5 Lectures]

Graph Matching, Illumination, Shadow, scene-Audio correlation [4 Lectures]

Various Priors (Color, Gradients, Natural Image) [4 Lectures]

Transform domain features.[4 Lectures]

Deep Fakes [7 Lectures]:

Counter Forensics, Adversarial Network, Deep Fakes [4 Lectures]

Motion-Audio Synchronization, Cloud based detection framework. [3 Lectures]

Textbook

1. Farid, H. (2016). Photo forensics. MIT Press.
2. Sencar, H. T., &Memon, N. (2013). Digital image forensics. Counter-forensics: attacking image forensics, 327-366.

Self Learning Material

Prof. Rita Singh, Computational Forensics and Investigative Intelligence, Carnegie Mellon University, http://forensics.cs.cmu.edu/courses/spring2018/schedule.html

Title	**3D Shape Analysis**	Number	EE7XXX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite	Fourier Analysis, Linear Algebra		

Objectives

The Instructor will:

Provide students an understanding of differential geometry tools isometry, geodesics, Laplace Beltrami Operator, and Functional Maps.

Learning Outcomes

The students are expected to have the ability to:

1. apply the learned geometry tools to solve practical 3D surface reconstruction problem.
2. generate 3D printable models from the unstructured point clouds.

Contents

Introduction to Differential Geometry [5 Lectures]: Basics of differential geometry of curve and surfaces and estimating the quantities such as normal and curvature.

Surface Representation and Reconstruction [9 Lectures]: 3D Surface Representation, Parametric and Non-parametric, Implicit, Signed Distance Function [3 Lectures]

Data structures for surface representation [1 Lectures]

3D surface reconstruction from point clouds. [5 Lectures]

Shape Analysis Tools [12 Lectures]:

Isometry, geodesics on triangle meshes [4 Lectures]

Scalar functions on shapes, discrete Laplace Beltrami operator [5 Lectures]

Heat Diffusion on Shapes [3 Lectures]

Shape Matching [12 Lectures]:

3D Shape Descriptors, Rigid and Non-rigid registration [5 Lectures]

Functional Maps, 3D Shape correspondences [5 Lectures]

Intrinsic Symmetry [2 Lectures]

Shape Repairing [4 Lectures]: Shape completion, generating printable 3D models from raw point clouds

Textbooks

1. Botsch, M., Kobbelt, L., Pauly, M., Alliez, P., &Lévy, B. (2010). Polygon mesh processing. CRC press.
2. Solomon, J. (2015). Numerical algorithms: methods for computer vision, machine learning, and graphics. CRC press.
3. O'neill, B. (2006). Elementary differential geometry. Elsevier.

Self Learning Material

1. Prof. Justin Solomon, Shape Analysis, Massachusetts Institute of Technology, http://groups.csail.mit.edu/gdpgroup/6838_spring_2019.html
2. Prof. Siddhartha Chaudhuri, Digital Geometry Processing, Indian Institute of Technology Bombay: https://www.cse.iitb.ac.in/~cs749/spr2017/

Preparatory Course Material

1. Prof. Gilbert Strang,Linear Algebra and Learning from Data, Massachusetts Institute of Technology, **https://math.mit.edu/~gs/learningfromdata/**

Socio-Digital Reality

Title	**Multimodal Interface**	Number	EE7XXX
Department	Electrical Engineering	L-T-P [C]	0–0–4 [2]
Offered for		Type	Specialization Core
Prerequisite			

Objectives

The Instructor will introduce students to the multimodal signals and interfaces.

Learning Outcomes

The students are expected to have the ability to design multimodal interface applications.

Contents

Introduction to principles of Multimodal Interfaces (2)
Basic haptic rendering and perception experiments using haptic interfaces (3)
AR and VR models (3)
EEG (1)
Eye Tracker (1)
Gesture (Kinect) (2)
Audio Assistance (2)

Textbooks

1. A. Bhardwaj and S. Chaudhuri, "Kinesthetic Perception: A Machine Learning Approach", Springer Publishers, 2017.
2. MC Lin and MA Otaduy (Eds), "Haptic Rendering: Foundations, Algorithms, and Applications", AK Peters, Ltd; London: 2008.
3. Aukstakalnis, Steve. Practical augmented reality: A guide to the technologies, applications, and human factors for AR and VR. Addison-Wesley Professional, 2016.

Self Learning Material

1. Prof. Gordon Wetzstein, Virtual Reality, Stanford University, https://stanford.edu/class/ee267/
2. Prof. Allison Okamura, Design and Control of Haptic Systems, Stanford University, http://web.stanford.edu/class/me327/

Title	**Speech Understanding**	Number	EE7XXX
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for		Type	Specialization Elective
Prerequisite			

Objectives

The Instructor will introduce students to basic concepts and techniques that help constitute speech understanding

Learning Outcomes

The students are expected to have the ability to design systems that can process speech signals with the goal of extracting useful semantic signal information.

Contents

Automatic Speech Recognition: HMMs for Acoustic Modeling [3 Lectures]
HMMs and Weighted Finite-State Transducers (WFSTs), WFSTs for Speech Understanding and Recognition, Basics of speech production, Tied-state HMMs [5 Lectures]
Feature analysis for Speech Understanding [2 Lectures]
Viterbi decoding algorithm and the Baum-Welch training algorithm [3 Lectures]
Gaussian Mixture Models (GMMs), context-dependent triphones for acoustic modelling [5 lectures]
Introduction to NN-based Acoustic Modeling, RNN-based models [4 Lectures]
Natural Language Processing: Word structure, semantics (lexical semantics, WordNet and WordNet based similarity measures) [5 lectures]
Classical parsing, parsing using Probabilistic Context Free Grammars and EM based approaches [5 lectures]
Language Modelling (basic ideas, smoothing techniques), RNN-based language models [4 lectures]
Distributional word representation, Supervised sentiment analysis [3 lectures]
Natural language inference [3 lectures]

Textbooks:

1. Gales, M., & Young, S. (2008). The application of hidden Markov models in speech recognition. Foundations and Trends® in Signal Processing, 1(3), 195-304.
2. Daniel Jurafsky and James H. Martin (2009). Speech and Language Processing: An Introduction to Natural Language Processing, Speech Recognition, and Computational Linguistics. 2nd edition. Prentice-Hall.

Self Learning Material

1. Prof. Bill MacCartney, Natural language understanding, Stanford University,https://web.stanford.edu/class/cs224u/
2. Prof. Preethi Jyothi, Automatic Speech Recognition, Indian Institute of Technology Bombay, https://www.cse.iitb.ac.in/~pjyothi/cs753/index.html