M. Tech. in Sensors and Internet of Things (SIoT)

Program Structure for first four semesters

Introduction

Last few decades had seen extensive growth in the electronic systems to make the life of humans smoother and easier with time. With enormous features available in various systems, a new era of engineering, Internet of Things (IoT), has gained interest. IoT is a network of connected things and people, which collects and communicates data from environment around them. To be able to do so, Sensors are the key components to communicate with surroundings. Applications of **Sensors and Internet of Things (SIoT)** include smart agriculture, transportation, environment monitoring, healthcare, and smart wearable. The M.Tech. Program in sIoT is especially designed for young innovators to provide them a breadth as well as depth for designing systems for the current era of sIoT. M.Tech.+Ph.D. Dual Degree program will have same course work as M.Tech. sIoT for first two years. However, Dual Degree program is specially designed to encourage talented and motivated B.Tech./M.Sc. students to undertake direct Ph.D. study in the area of sIoT.

Objective

To produce skilled graduates with exposure to current era of SIoT and deeper understanding of the subject components. The graduates will eventually be contributing to variety of domains including smart agriculture, transportation, environment monitoring, healthcare, and smart wearable.

Program's Scope

The objective is to develop broad IoT systems and this program will be offered with four Primary verticals.

- Sensors and Sensing Technologies
- Circuits and Systems
- Communication and Networking
- Embedded systems

The program will offer deeper theoretical learning through various verticals by theory and laboratory courses. Hands on experiments and projects will be offered to enhance the learning. For Dual Degree Ph.D., ~2 additional years will be dedicated towards research contributions.

Graduate attributes

- Ability to follow multidisciplinary approach for design and implementation of systems, involving various domains of Engineering, Sciences, and Humanities.
- Skills to design and develop various sensors and related interfacing circuitry for IoT
- Ability to develop design, simulation, and implementation schemes based on the knowledge acquired from coursework.
- Skills to implement IoT sensor platforms for applications in the area of environment, health, agriculture, and other novel applications.
- Skills to undertake high quality academic and industrial research in Sensors and IoT

Learning outcomes

- Strong understanding of fundamentals of Sensing and Sensor Devices
- Ability of designing Digital and Analog interface circuits used for SIoT
- Capability of interfacing Sensors for IoT applications
- Development and use of emerging Sensors for IoT Technology
- Understanding of fundamentals of wireless communications to design Sensor Nodes
- Implementation of IoT platforms using embedded systems
- Understanding of uses and risks related to IoT devices

Program's Structure

Overall Structure

Category	*M.Tech Compulsory (MC)*	*M. Tech Elective (ME)*	*M. Tech Open (MO)*	M. Tech Project (MP)	Total
Credits	19	17	6	16	58

Semester wise distribution of credits

Cat.	*Course Title*	*L-T-P*	*Cr.*		*Cat.*	*Course Title*	*L-T-P*	*Cr.*
I Semester					**II Semester**			
MC	***Sensors and Measurement***	3-0-0	3		**MC**	***Data communication and Networking***	3-0-0	3
MC	***Microsystems Fabrication Technology***	3-0-0	3		**MC**	***Digital and Systems-on-Chip Design***	3-0-0	3
MC	***Analog and Interfacing Circuits***	3-0-0	3		**MC**	***VLSI Design Lab***	0-0-2	1
MC	***Introduction to Internet of Things***	1-0-0	1		ME	*Program Elective-2*	3-0-0	3
MC	***Sensors and IoT Lab***	0-0-2	1		ME	*Program Elective-3*	3-0-0	3
ME	*Program Elective-1*	3-0-0	3		ME	*Program Elective-4*	3-0-0	3
NG	*Technical Communication*	1-0-0	1		NG	*Professional Ethics*	1-0-0	1
Total (Graded + Non-graded)			**15**		*Total (Graded + Non-graded)*			**17**
Winter Term								
MC	***Winter Internship***		1					
		Total	**1**					
III Semester					**IV Semester**			
MP	Project-1		5		MP	Project-2		11
ME	*Program Elective-5*	3-0-0	3		MO	*Open Elective-2*	3-0-0	3
ME	*Program Elective-6*	2-0-0	2		NG	*IP Management and Exploitation*	1-0-0	1
MO	*Open Elective-1*	3-0-0	3					
NG	*Systems Engineering and Project Management*	1-0-0	1					
		Total (Graded+ Non-graded)	**14**				*Total (Graded+ Non-graded)l*	**15**

Winter Internship is designed for hands-on-exposure in micro-fabrication technology for sensors and actuators

List of Program Electives

Course Title	*L-T-P*	*Credits*		*Course Title*	*L-T-P*	*Credits*
First/Third Semester				***Third Semester***		
Flexible and Printed Electronics	3-0-0	3		*Advanced Digital Signal Processing*	3-0-0	3
Digital VLSI Design	3-0-0	3		*Neuromorphic Computing and Design*	3-0-0	3
Wireless Communication	3-0-0	3		*Fog and Edge Computing*	3-0-0	3
Antenna Engineering	3-0-0	3		*Vehicular Ad Hoc Networks*	3-0-0	3
				Machine Learning 1	3-0-0	3
				Selected Topics in Sensors & IoT I	1-0-0	1
Second Semester				***Fourth Semester***		
Image Sensor Design and Applications	3-0-0	3		*Resource Constrained AI*	3-0-0	3
RF IC Design	3-0-0	3		*Microfluidics Technology*	3-0-0	3
Embedded Systems Design	3-0-0	3		*Selected Topics in Sensors & IoT II*	2-0-0	2
Active Filter Design	3-0-0	3		*Selected Topics in Sensors & IoT III*	3-0-0	3
Millimeter-wave Technology	3-0-0	3				
Nano Sensors	3-0-0	3				

Open electives: These can be taken from the existing program electives or any other course of same level from the institute

Course Title	**Sensors and Measurements**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech. 1st year	Type	Compulsory
Pre-requisite	Semiconductor Devices		

Objective

The Instructor will:

1. Introduce the students to sensors, as transducers from physical parameters to signals
2. Explain the sensing principles for displacement, force, pressure, acceleration, temperature, optical radiation, nuclear radiation
3. Explain the sensor range, sensitivity, accuracy, repeatability, noise

Learning Outcomes

Students are expected to have the ability to

1. Understand fundamental principles of sensing technology,
2. Design various sensors and implementation
3. Understand Nondestructive characterization methods

Contents

EEL7XX1: Sensor characteristics [1-0-0]

(Fractal 1) Definitions, terminology, classification, Static vs dynamic properties of transducers, Transfer functions, Ideal and realistic transducer models, Resolution, linearization, dynamic range, detection threshold, Selectivity & sensitivity, Calibration, Errors of the experimental measurements, Noise: electronics, environmental & internal (14 lectures)

EEL7XX2: Physical Principle of Sensing [1-0-0]

(Fractal 2) Capacitance, Magnetism, Induction, Resistance, Piezoelectric effect, Pyroelectric effect, Hall effect, Thermoelectric effect, Temperature and thermal properties of materials and heat transfer, Optics, Fiber optics and waveguides (14 lectures)

EEL7XX3: Sensor Interface and Applications [1-0-0]

(Fractal 3) Input characteristics of interface circuits, Amplifiers, Light to voltage converters, Capacitance to voltage converters, Bridge Circuits, Excitation circuits. Case Studies: Inertial Sensors (Accelerometer & gyroscope), Healthcare Sensors (Glucometer, ECG & MRI), Smart building Sensors (Smoke & occupancy sensors) (14 lectures)

Text Books

1. Jacob Fraden, (2010), Handbook of Modern Sensors, 5th Edition, Springer.
2. J. W. Gardner, (1996), Microsensors, Principles and Applications, 1st Edition, Wiley.
3. S. M. Sze, (1994), Semiconductor Sensors, 1st Edition, Wiley.

Course Title	**Analog and Interfacing Circuits**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech. 1st year	Type	Compulsory
Pre-requisite	Digital and Analog Electronics		

Objectives

The Instructor will:

1. Familiarize students with the concepts of Analog IC Design and give them a comprehensive overview of various amplifiers.
2. Familiarize the students with different building blocks of a mixed signal interface circuit design essential for sensors and IoT.

Learning Outcomes

Students are expected to have the ability to:

1. Understand fundamental principles of CMOS Analog IC Design and interfacing of analog signals with the digital signal processing circuits.
2. Apply the circuit design fundamentals for IoT applications.
3. Work on design tools like Cadence/Mentor Graphics

Contents

EEL7XX1: Fundamentals of Analog Circuits and Design [1-0-0]

(Fractal 1) Introduction to Analog VLSI and design issues in CMOS technologies, MOS models, SPICE Models, Single stage amplifiers, Biasing circuits, Voltage and Current reference circuits, Feedback analysis, Multistage amplifiers, Mismatch and noise analysis, Differential amplifiers, Oscillators (14 Lectures)

EEL7XX2: Readout Electronics [1-0-0]

(Fractal 2) *Switch capacitor circuits:* Principles and applications in filter design; switches and related design issues, variable gain amplifier, low noise and high speed amplifier topologies. *Analog to digital converters:* Types of ADCs, static and dynamic characteristics; track and hold, and sample and hold circuits; comparators; detail design analysis for successive approximation register (SAR) ADCs, discrete-time and continuous time sigma-delta ADCs (14 Lectures)

EEL7XX3: Digital to Analog Converters Design [1-0-0]

(Fractal 3) *Digital to Analog Converters:* Voltage-based DACs; charge-based DACs; current-based DACs – binary and thermometer currents. *Phase-locked loop*: Basics; PLL dynamics; voltage controlled oscillator, frequency synthesis. Applications: Wearable Biomedical IoT nodes (14 Lectures)

Text Books

1. Razavi, B., (2016), *Design of Analog CMOS Integrated Circuits*, 2nd Edition, McGraw-Hill Education.
2. R. Jacob Baker, H.W.Li, and D.E. Boyce, (2009), – *CMOS Circuit Design ,Layout and Simulation*, 2nd Edition, Prentice-Hall of India
3. David A. Johns, Ken Martin, (2013), "Analog Integrated Circuit Design", 2nd Edition, John Wiley and Sons.

Self Learning material

1. Shanthi Pavan, VLSI Data Conversion Circuits, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117106034/
2. Nagendra Krishnapura, Analog Integrated Circuit Design, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117106030/

Preparatory Course Material

1. P. E. Allen, D. R. Holberg (2013), *CMOS Analog Circuit Design*, 3rd Edition, Oxford University Press.
2. R. Gregorian, G. C. Temes, (2008), "*Analog MOS Integrated Circuits for Signal Processing*", John Wiley and Sons.

Course Title	**Microsystems Fabrication Technology**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech. 1st year	Type	Compulsory
Pre-requisite	Semiconductor Devices		

Objectives

The Instructor will:

1. Introduce to the students the essentials of micro-electronics fabrication technology required for the realization of integrated circuits and transducers & actuators.
2. Introduce the basic concepts of MEMS design, fabrication process integration and advanced micro-machining techniques for high aspect ratio MEMS structures.

Learning Outcomes

Students will have the capability to :

1. Understand the unit fabrication processes for ICs and MEMS
2. Design and fabricate MEMS based sensors and actuators

Contents

Unit processes in fabrication of ICs and MEMS: Clean room practices, Crystal growth techniques, wafer preparation and shaping, chemical cleaning, thermal oxidation, diffusion, ion implantation, photolithography, Thin film deposition, Etching *(18 lectures)*

Unit processes specific to MEMS: Surface and bulk micro-machining, DRIE, LIGA, and packaging *(12 lectures)*

Case studies of MEMS: Basic concepts of Beam/diaphragm mechanics, electrostatic actuation and fabrication, 'process design' for selected MEMS based sensors and actuators such as Comb drives, touch sensor, pressure sensor, RF MEMS Switches, Electric / Magnetic Field sensor etc.
(12 lectures)

Text books:

1. Tai-Ran Hsu, (2017), *MEMS & Microsystems Design and Manufacture*, Indian Edition, Tata McGraw-Hill
2. M. Bao, (2005), *Analysis and Design Principles of MEMS Devices*, 1st Edition, Elsevier
3. J. D. Plummer, M. D. Deal, and P. B. Griffin (2009), *Silicon VLSI technology: Fundamentals, practice, and modelling*, 1st Edition, Prentice Hall

Self learning material

1. Marc J. Madou, (2011), *Fundamentals of Microfabrication and Nanotechnology*: *The Science of Miniaturization*, 3rd Edition, CRC Press.
2. M. Sze, (2003), *VLSI Technology*, 2nd edition McGraw Hill Education.

Preparatory course material

1. Sensors and Actuators (Elsevier)
2. J. Micromechanics and Micro engineering (IOP)

Title	**Introduction to Internet of Things**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	1–0–0 [1]
Offered for	M. Tech. 1st year	Type	Compulsory
Prerequisite			

Objectives

The Instructor will:

1. Provide overview of applications of IoT and relevant technologies

Learning Outcomes

The students are expected to have the ability to:

1. Identify and integrate different components required for IoT applications

Contents

Introduction to IoT: Sensing, Actuation, Basics of IoT Networking (2 Lectures)
IoT Architecture, Communication Protocols for IoT (2 Lectures)
Sensor Networks: Wireless Sensor Network, Sensor nodes (2 Lectures)
Machine to machine Communication: Introduction, Node types and M2M Applications, Integration of Sensors and Actuators for Implementation of IoT (4 Lectures)
Introduction to Cloud, Fog, and Edge Computing, Smart cities and Smart homes, Industrial IoT (4 Lectures)

Textbook

1. Kamal, R., (2017), *Internet of Things - Architecture and Design Principles*, 1st Edition, Mcgraw Hill.

Preparatory Course Material

1. Misra, S., *Introduction to Internet of Things*, NPTEL Course Material, Department of Computer Science and Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/106105166/

Title	**Data Communication and Networking**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech. 1st year	Type	Compulsory
Prerequisite	Fundamentals of Wireless Communications		

Objectives

The Instructor will:

1. Expose the students to distinguishing features of wireless networks

Learning Outcomes

The students are expected to have the ability to:

1. Design and optimize wireless network architectures.
2. Implement security techniques for wireless networks.

Contents

Fundamentals: Layered architecture overview, data communication techniques, motivations for cross-layer protocol design, motivations for performance analysis, forward error correction and re-transmission performances (7 Lectures)

Network layer and topology design: Markov and semi-Markov processes, Little's theorem, M/M/m/k, M/G/1 systems, priority queueing, network of queues, network traffic behavior, routing algorithms and analysis, distributed networks, design constraints, bounded latency networks, optimization, cognitive networks (10 Lectures)

Network Management: Power management, time synchronization, localization, energy-efficient protocols for sensor networks (7 Lectures)

Mechanisms to improve performance: Self-Organizing Network, Software-Defined Networking (7 Lectures)

Transport and Application Layers: congestion control and quality of service, scheduling, multimedia, key aspects and design issues (7 Lectures)

Reliability and security: Security requirement and attacks, Encryption techniques, reliable and secure communication protocols (4 Lectures)

Textbook

1. Dargie, W., and Poellabauer, C., (2010), *Fundamentals of Wireless Sensor Networks: Theory and Practice*, Wiley
2. Stallings, W., (2007), *Data and Computer Communications*, 8th Edition, Pearson
3. Bertsekas, D. P. and Gallager, R. G., (1992), *Data Networks,* 2nd Edition, Prentice Hall

Self-Learning Material

1. Mishra, S., *Wireless Adhoc and Sensors Networks*, NPTEL Course Material, Department of Electrical and Electronics Communication Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/106105160/
2. Zou, Y., Zhu, J., Wang, X., and Hanzo, L., "A Survey on Wireless Security: Technical Challenges, Recent Advances, and Future Trends," in *Proceedings of the IEEE*, vol. 104, no. 9, pp. 1727-1765, Sept. 2016.
3. W. Xia, Y. Wen, C. H. Foh, D. Niyato and H. Xie, "A Survey on Software-Defined Networking," in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 1, pp. 27-51, First quarter 2015.

Preparatory Course 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

Course Title	**Digital and Systems-on-Chip Design**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech. 1st year	Type	Compulsory
Pre-requisite	Digital Logic and Design		

Objectives

The Instructor will:

1. Make the students analyze the functional and nonfunctional performance of the system early in the design process to support design decisions.
2. Make the students appreciate issues in system-on-a-chip design associated with co-design, such as intellectual property, reuse, and verification.
3. Explain the hardware, software, and interface synthesis.

Learning Outcomes

The students are expected to have the ability to:

1. Analyze hardware/software tradeoffs, algorithms, and architectures to optimize the system based on requirements and implementation constraints.
2. Understand issues in interface design.
3. Use co-simulation to validate system functionality.

Contents

Digital Design using Verilog and VHDL: Introduction to ASIC design, combinational and sequential circuit design process, Finite state machines, Modelling styles, RTL models, Memory models. *Programmable logic devices and FPGAs:* PALs, PLDs, FPGA programming concepts and techniques, design synthesis using FPGA kits (14 lectures)

System-level and SoC design methodologies and tools; HW/SW co-design: analysis, partitioning, real-time scheduling, hardware acceleration; Virtual platform models, co-simulation and FPGAs for prototyping of HW/SW systems; Transaction-Level Modeling (TLM), Electronic System-Level (ESL) languages: SystemC; High-Level Synthesis (HLS): allocation, scheduling, binding, resource sharing, pipelining; SoC and IP integration, verification and test. ARM-based System-on-Chip Design. (28 lectures)

Text Books

1. Unsalan, C., Tar, B., (2017), *Digital System Design with FPGA Implementation Using Verilog and VHDL*, McGraw-Hill
2. D. Black, J. Donovan, (2010), *SystemC: From the Ground Up*, 2nd Edition, Springer.
3. D. Gajski, S. Abdi, A. Gerstlauer, G. Schirner, (2009), *Embedded System Design: Modeling, Synthesis, Verification*, Springer

Preparatory Course material

1. Nelson, V.P., Carroll, B.D., Nagle, H.T., Irwin, J.D., (2020), *Digital Logic Circuit Analysis and Design*, 2nd Edition, Pearson
2. G. De Micheli, (2017), *Synthesis and Optimization of Digital Circuits*, McGraw-Hill.

Title	**Flexible and Printed Electronics**	Number	**EEL7XX0**
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.

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: Evolution of Flexible Electronics, review of cutting edge research on electronics that can be flexible, plastic, stretchable, conformable or printed. Electronic materials, components and systems, applications for IoT **(2 Lectures)**

Materials, Processing, and Manufacturing: Various semiconductors, dielectric, and conducting materials, Organic semiconductors, from chemical bonds to bands, Charge injection and transport, Examples of printable functional materials , Thin-film Deposition and Processing Methods for Flexible Devices, Solution-based Patterning Processes; Ink-jet printing, gravure and other processes, surface energy effects, multilayer patterning **(12 Lectures)**

Flexible Thin-Film Transistors and Circuits: Thin-Film Transistor; Device structure and performance, Electrical characteristics, parameter extraction, characterization methods for rigid and flexible devices, electrical stability, printed transistors; organic/polymer, metal-oxide, electrolyte gated, Case studies; submicrometer OTFTs and gravure printed OTFTs, 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 **(14 Lectures)**

Other Flexible Devices and System Integration: Organic Light Emitting Diodes, Organic Solar Cells, thin flexible OLED displays, OLED lighting, smart wallpaper, sensors, logic, and memory, RFID tags, Latest applications of printed electronics, Encapsulation, Roll to roll printing processes, Integration Issues, and Designs for Future **(14 Lectures)**

Textbook

1. G. Nisato, D. Lupo, S. Ganz (Editors) (2016), *Organic and Printed Electronics: Fundamentals and Applications*, CRC Press
2. Large Area and Flexible Electronics, Mario Caironi & Yong-Young Noh (Editors (2015), WILEY-VCH
3. Wong, William S., and Alberto Salleo, (Eds.) (2009) *Flexible electronics: materials and applications*. Vol. 11. Springer

Self Learning Material

1. Recent Journal Papers form Flexible and Printed Electronics, IOP, and Organic Electronics, Elsevier

Title	**Antenna Engineering**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV Year, M. Tech., Ph.D.	Type	Elective
Prerequisite	Electromagnetic Theory, Microwave Engineering		

Objectives

The Instructor will:

1. Introduce the various concept of antenna design.
2. familiarize the students with the application of different type of antennas

Learning Outcomes

The students are expected to have the ability to:

1. Design low profile antennas and high gain antenna arrays for practical applications
2. Utilize simulation software e.g. HFSS, CST etc. for designing Antenna systems and test RF and microwave antennas

Contents

Introduction to Antennas: Radiation mechanism, Current distribution on a thin wire antenna, Review of Antenna Parameters; Friis Transmission formulae, Radar Range equation (7 Lectures)

Radiation Integrals and Auxiliary Potential Function Vector potential for electric current source and magnetic current source, inhomogeneous vector potential wave equation, duality theorem, reciprocity theorem (3 Lectures)

Design of Dipole Antenna Design of Infinitesimal dipole, small dipole, half-wavelength dipole (4 Lectures)

Microstrip antenna Rectangular patch antenna, feeding methods, transmission line model, cavity model, Circular Patch Antenna (4 Lectures)

Low-profile Antenna Application: Mobile handset antenna- helical wire and variants; electrically small antenna; power factor, quality factor and bandwidth; radiation efficiency and realized gain; PIFA;; On-chip antenna; SAR measurement and miniaturization; GPS and Bluetooth antenna; medical application- antennas for medical imaging; heating; sensing; Automobile antennas- MAST antenna; Window glass antenna; Panel Antenna; (10 Lectures)

Design of Antenna Arrays Analysis of Two element array, N-element linear array (uniform and nonuniform amplitude excitation: Binomial, Dolph-Tschebyscheff, Taylor distribution), planar array, Phased Array (5 Lectures)

Aperture Antenna Field equivalence principle, Radiation equation, Rectangular aperture, circular aperture, Babinet's principle, Sectoral horn antenna, Pyramidal Horn antenna (6 Lectures)

Antenna Measurement Antenna Ranges, Radiation Pattern measurement, Gain measurement (absolute gain method, gain comparison method), Directivity measurement (3 Lectures)

Textbook

1. Balanis C. A., Antenna Theory, Analysis and Design, 4th edition, Wiley Press, 2016
2. Krauss J. D., Antennas and Wave Propagation, 4th edition, Tata McGraw-Hill Education, 2006
3. Elliott R. S., Antenna Theory and Design, Wiley Press, 2006

Self Learning Material

1. 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. NPTEL Lectures: Microwave Theory and Techniques, (Dr. Girish Kumar, IIT Bombay) https://nptel.ac.in/courses/108101112/

Title	**Digital VLSI Design**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV, M.Tech., Ph.D.	Type	Elective
Prerequisite	Digital Electronics, Knowledge of MOS device physics		

Objectives

The Instructor will:

- Introduce the basics of digital circuit design methods.
- Explain the 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:

- Design and optimize digital circuits with different quality metrics: cost, speed, power dissipation, and reliability.
- Learn about the major building blocks of digital systems

Contents

- *Introduction:* Review of VLSI, Historical Perspective, Issues in Digital IC design, Quality metrics. (2 Lectures)
- *Manufacturing:* CMOS technology, Layout design & design rules, IC Packaging, future trends in process technology. (2 Lectures)
- *Devices and Interconnects:* MOS devices, MOS transistor models, Technology Scaling, Effect of Process variations, Interconnect and wire models. (4 Lectures)
- *CMOS Circuits:* CMOS Inverter, Static and Dynamic Behaviour, Propagation delay, noise margins, and power dissipation, Impact of technology scaling, logical efforts. (7 Lectures)
- *Designing combinational logic gates:* Static CMOS design, Ratioed Logic, Pseudo NMOS, Pass Transistors Logic, Dynamic CMOS design, speed and power dissipation, choosing a logic style (7 lectures).
- *Design of sequential logic circuits:* Static Latches and Registers, Dynamic Latches and Registers, Alternative Register styles, pipelining, choosing a clock strategy. (3 Lectures)
- *Timing Issues in Digital Circuits:* Timing classification, Synchronous Design, Synchronous timing basics, Skew and Jitter, clock distribution techniques (5 Lectures).
- *Designing Arithmetic Blocks:* Data paths in Digital Processor Architecture, Adder, Multiplier, Shifter, power and speed tradeoff. (3 Lectures).
- *Designing Memories and Array Structures:* Memory Classification, Memory Architecture and Building Blocks, Memory core, Read only Memory, Read-write Memories, Memory peripheral circuitry, Decoders, Sense Amplifiers, Buffers, reliability, power dissipation, future trends validation and test (7 Lectures).
- Implementation strategies for digital ICs, Design Verification, Validation and Test, Introduction to HDL. (2 Lectures)

Textbook

1. Jan M. Rabaey, Anantha Chandrakasan, and Borivoje Nikolic, (2016), *Digital integrated Circuits, A design perspective*, 2nd Edition, 2nd Edition, Pearson.
2. Neil H.E. Weste, David Money Harris, (2010), *CMOS VLSI Design: A Circuits and Systems Perspective*, 4th Edition, Pearson.
3. Sung-Mo-Kang, Yusuf Leblebici, (2016), CMOS Digital Integrated Circuits Analysis & Design, 4th Edition, Mc-Graw Hill.

Self Learning Material

1. Jan M. Rabaey, Anantha Chandrakasan, and Borivoje Nikolic, online Video lectures http://bwrcs.eecs.berkeley.edu/Classes/icdesign/ee241_s01/Lectures/

Title	**Wireless Communications**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV, M.Tech., Ph.D.	Type	Elective
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: Modelling of wireless channels; space, time and frequency channel coherence; input/output channel models for single and multi-antenna systems (7 lectures)

Diversity: Digital modulation and its performance in fading; inter-symbol interference; realizing diversity: time diversity, frequency diversity, antenna diversity; code design for wireless channels (14 lectures)

Wireless Channel Capacity: Capacity of the Gaussian channels; capacity of fading channels (7 lectures)

Multiuser system design: Multiple access and random access techniques; multiuser channel capacity (7 lectures)

Ad hoc wireless network: design principles, protocol layers, network capacity limits, and energy-constrained networks. (7 lectures)

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

1. 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/

2. Zheng, L. and Gallager, R., *Principles of Digital Communications I*, MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-450-principles-of-digital-communications-i-fall-2006/

Title	**Image Sensor Design and Applications**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech. IV, M. Tech, Ph.D.	Type	Elective
Prerequisite	Analog electronics		

Objectives

The Instructor will:

1. Introduce the design and analysis of CMOS image sensors.
2. Explain the readout electronics behind the camera.
3. Provide the knowledge of performance measures and tradeoffs involved in the camera design.

Learning Outcomes

The students are expected to have the ability to:

1. Design and develop CMOS image sensor including the sensing mechanism and signal chain of the camera.
2. Implement different techniques required for high dynamic range camera, high frame rate, low noise camera, time of flight 3D cameras etc.

Contents

Introduction to photodetectors: Photodiode and photogate, photocurrent, dark current, quantum efficiency, spectral response and photo-conversion principles (5 Lectures).
Introduction to Charge coupled devices and CMOS image sensors: Operation, performance metrics, noise and its types, spatial resolution and modulation transfer function. Concept of exposure triangle including aperture, shutter speed and ISO, color filters, Bayer pattern, Shutters and its types, motion blur, hard and soft reset, Introduction to imaging optics (8 Lectures).
Readout electronics and image sensor characterization: Readout and its types, design tradeoffs and challenges, analysis of the signal path behind the camera, variable gain amplifiers, double sampling circuits, ADCs, reference circuits including BGR and LDO, clock generation circuits including PLL and delay elements, floor planning, placement and routing, image sensor characterization. Introduction to wire bonding, packaging, lens and color filters for product level design (15 Lectures).
Emerging trends: High speed cameras, high dynamic range cameras, 3D cameras for background light subtraction and depth estimation. Concepts of Polarization imaging, low light imaging, machine vision, backside illumination, stacked technology, target tracking (10 Lectures).
Color Processing: Color demosaicing, color correction and white balance (2 Lectures).
Applications: Smart city, health care, autonomous vehicles, sports, motion detection, surveillance (2 Lectures).

Textbook

1. Jun Ohta, (2007), *Smart CMOS Image sensors and Applications*, CRC press.

Self Learning Material

1. O. Yadid Pecht and R. E. Cummings (2004), *CMOS imagers: From Photo transduction to Image processing,* Springer.
2. Image sensors blog http://image-sensors-world.blogspot.com/

Preparatory Course Material

1. El Gamal, Abbas, and Helmy Eltoukhy (2005) "CMOS image sensors." *IEEE Circuits and Devices Magazine* vol. 21, no. 3, pages 6-20.
2. Fossum, Eric R. (1997) "CMOS image sensors: Electronic camera-on-a-chip." *IEEE transactions on electron devices* vol. 44. no. 10, pages 1689-1698.

Title	**Radio Frequency Integrated Circuit Design**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech, and PhD Students	Type	Elective
Prerequisite	Analog electronics, Communication engineering, Microwave engineering.		

Objectives

1. To introduce the students with the integrated circuit designing at radio frequencies.
2. Introduction of various circuits and building blocks for communication applications.

Learning Outcomes

1. Understanding the design of integrated circuits at high frequencies.
2. Practical implementation of various circuits required to build a transceiver system.
3. Learning about the design of various active components like mixers, LNAs, power amplifiers at RF and microwave frequencies.

Contents

Communication System Overview: Modulation, Mobile Systems, Multiple Access Techniques, Wireless Standards. (3 lectures)
Noise: Noise spectrum, effect of transfer function on noise, noise in a circuit, device noise. (4 lectures)
Transceiver Architectures: Heterodyne Receivers, Direct-Conversion Receivers, Image Reject and Low IF Receivers, Transmitter Architectures. (4 lectures)
Concepts of RF Design: Wave Guides and Transmission Lines, coupled lines, S-Parameters, Smith Chart, single and double stub impedance matching, Two-port gain and stability analysis. (10 lectures)
Amplifier Design: Concepts of nonlinearity, time variance and IIP3, model of MOS transistors and BJT at high frequencies, wideband amplifiers, constant gain amplifier, constant noise figure amplifier, power amplifiers, combining networks. (8 lectures)
Oscillators and Voltage Controlled Oscillators: Basic topologies VCO and definition of phase noise. Noise-power trade-off, quadrature and single-sideband generators. (5 lectures)
Mixers: Mixer Noise figure, port to port feed-through, single-balanced and double balanced mixers. (4 lectures)
Introduction to Phase-Locked Loops: Type I and Type II PLL's, PLL Non-idealities. (4 lectures)

Textbooks

1. T. H. Lee, the Design of CMOS Radio-Frequency Integrated Circuits. Cambridge, UK: Cambridge University Press, 1997.
2. B. Razavi, RF Microelectronics, 2^{nd} Edition, Pearson Education, 2014.
3. G. Gonzalez, Microwave Transistor Amplifiers: Analysis and Design, 2^{nd} edition, Pearson, Aug-1996.

Self Learning Materials

1. RF Integrated Circuits, NPTEL, Dr. S. Chatterjee, IIT Delhi, http://nptel.ac.in/courses/117102012/#
2. High Speed Communication Circuits, MIT, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-776-high-speed-communication-circuits-spring-2005/lecture-notes/

Preparatory Course Materials

1. B. P. Lathi, Z. Ding, Modern Digital and Analog Communications Systems, 4^{th} edition, Oxford university press, July-2017.
2. D. M. Pozar, Microwave Engineering, 4th edition, New York, NY, USA: Wiley, 2011.

Title	**VLSI Design Lab**	Number	**EEP7XX0**
Department	Electrical Engineering	L-T-P [C]	0–0–2 [1]
Offered for	M. Tech. 1st year	Type	Compulsory
Prerequisite			

Objective

1. To introduce students with the designing of combinational and sequential circuits.
2. To familiarize students with the designing of various building blocks related to analog design.
3. To familiarize students with the process design kits and tools like Cadence/Mentor Graphics.
4. To aware the students with pre-layout and post-layout simulations.

Learning Outcomes

1. Students will be able to understand the design issues and challenges involved in practical design.
2. Knowledge of design tools like Cadence and process design kits.
3. Students will be able to perform different analysis (DC, AC, transient etc.) and design steps involved in tape-out.

Contents

- **Experiments related to digital design**
    - Design of static logic gates with passive and active load, plot voltage transfer characteristics and calculate noise margin.
    - Design and layout of switches including pass transistor and transmission gates.
    - Combinational circuit design with placement and routing considerations.
    - Implementation of different functions with dynamic and domino logic style.
    - Sequential logic design, clock issues and timing constraints.

- **Experiments related to analog design**
    - Design of common source, common gate and common drain amplifier for given specifications.
    - Design problems related to wide swing, high gain, high bandwidth, low power and low noise differential amplifier.
    - Design of a differential amplifier with current-mirror/active load.
    - Design of a high speed, low power voltage mode and current mode comparators.
    - Design and perform DC, AC, noise, transient analysis of a two-stage op-amp.

Title	**Sensors and IoT Lab**	Number	**EEP7XX0**
Department	Electrical Engineering	L-T-P [C]	0–0–2 [1]
Offered for	M. Tech. 1st year	Type	Compulsory
Prerequisite			

Objective
1. To introduce students with sensors fabrication
2. To familiarize students with measurement instruments like Spectrum and Vector Network Analyzer
3. To introduce students with various kits and components required for IoT applications

Learning Outcomes
1. Familiarization with sensor fabrication process and characterization
2. Handling high frequency measurement instruments
3. Implementation of various circuits required to build a transceiver

Contents

The lab course will be dependent on the various core and elective components of the program. There will be a scope for modifying the contents depending on the recent developments in technology. Experiments from some of the following topics will be part of this lab.

- Implementation of Signal Conditioning Circuits
- Implementation of IoT components using Hardware/Software
- Sensor interfacing using off-the-shelf components
- Sensor Design, Fabrication and Characterization (Part of this in winter internship)
- RF components characterization; Antennas and RF amplifiers
- Implementation of real time examples of IoT using Embedded Systems
- Selected experiments from Communication Systems
- Recent topics of interest

Title	**Nano Sensors**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV year), M.Tech, and Ph.D.	Type	Elective
Prerequisite			

Objective

The Instructor will:

1. Make the students understand the importance of nanoscale materials for sensing applications.
2. Explain the approaches used for characterizing sensors based nanomaterials.
3. Teach the approaches used for tailoring nanomaterials for a specific sensing application.

Learning Outcomes

Students are expected to learn

1. Identify the most appropriate Nanosensors for scientific applications.
2. Understand the underlying sensing phenomena used in nanosensors;
3. Reliably process, evaluate and interpret the information presented by nanosensors;

Contents

Nanomaterials and Properties: Nanoscale physics for quantum dot, nanowire and quantum wells; Properties of nanomaterials; nanomechanical oscillators, nano(bio)electronics, nanoscale heat transfer; fluids at nanoscale **(8 lectures)**

Nanoscale Characterization: Examination of nanoscale characterization approaches including imaging, scattering, and spectroscopic techniques and their physical operating mechanisms. Microscopy (optical and electron: SEM, TEM); scattering & diffraction; spectroscopies (EDX, SIMS, Mass spec, Raman, XPS, XAS); scanning probe microscopes (SPM, AFM); particle size analysis **(8 lectures)**

Nanofabrication: Basic engineering principles of nanofabrication. Topics include: photo-, electron beam and nanoimprint lithography, block of copolymers and self-assembled monolayers, colloidal assembly, biological nanofabrication **(8 lectures)**

Nanosensors: Nanosensors based on metal nanoparticles, semi-conductor nanowires and nanocrystals and carbon nanotubes etc. **(10 lectures)**

Case Studies of Nanosensors: Optical, mechanical and chemical sensors based on nanomaterials, Hybrid nanomaterial-based sensors, Quantum wells based IR sensors **(8 lectures)**

Text Books

1. Mindy Adams, (2016) Engineered Nanomaterials: Modeling, Methodologies and Applications, Wellford Press
2. John Hutchison, Angus Kirkland, (2007) Nano characterisation, RSC
3. Roger George Jackson, (2004) Novel Sensors and Sensing, CRC Press

Preparatory Course Material

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

Title	**Active Filter Design**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech, and Ph.D.	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide theoretical and practical aspects of active filter design

Learning Outcomes

The students are expected to have the ability to:

1. Design analog filters using active components.
2. Design customized filter for specific applications using approximation theory

Contents

Review of Network Theorems including Reciprocity and Tellegen's theorem, scattering parameters, properties of lossless passive networks. (4 Lectures)
Butterworth approximation; Chebyshev approximation; synthesis of Butterworth and Chebyshev filters; odd versus even order filters; sensitivity of lossless LC ladder filters Frequency transformations; inverse Chebyshev and elliptic approximations; synthesis of inverse Chebyshev and elliptic filters; Darlington synthesis; signal flow graphs of ladder filters. (20 Lectures)
Opamp-RC implementation; Gm-C implementation; switched-capacitor implementation; minimum required performance of active components. Tuning of filters; transmission line based filters: using high-Z low-Z technique, using Kuroda's identities; bi-quad based design approaches and drawbacks; Tow-Thomas biquad, Sallen-Key biquad. (18 Lectures)

Textbook

1. Schaumann, R., Xiao, H., Valkenburg, M.V., (2009), "*Design of Analog Filters 2nd Edition*" , 2nd Edition, Oxford University Press
2. *Tsividis, Y.P., Voorman, J.O., (1993), "Integrated Continuous-Time Filters: Principles", Design, and Applications, IEEE*

Preparatory Course Material

1. Pavan, S., *Active Filter Design*, Department of Electrical Engineering, Indian Institute of Technology Madras, http://www.ee.iitm.ac.in/videolectures/doku.php?id=ee534:start

Title	**Millimeter-wave Technology**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech, and PhD Students	Type	Elective
Prerequisite	Electromagnetic theory, Microwave engineering		

Objectives

The Instructor will:

1. introduce the students with the phenomenon and circuit characteristics at mm-wave frequency ranges.
2. introduce various guiding structures, antennas, and switches at mm-wave frequencies

Learning Outcomes

The students are expected to have the ability to:

1. Understand the design problems and challenges at mm-wave frequencies
2. design various mm-wave guiding structures, passive and active circuits

Contents

Introduction to millimeter-wave technology: mm-wave frequency bands, atmospheric losses, application of mm-waves, Propagation and path losses, Friis equation, link budget and power budget calculation. (4 lectures)

Novel Guiding structures for mmwave circuits: losses in planar circuits (conductor loss, leakage loss, dielectric loss, surface waves), Air filled waveguides, dielectric guides, NRD guide, substrate integrated waveguides (SIW), Substrate Integrated NRD (SINRD), Gap Waveguide, dielectric image line, planar air filled waveguide, Waveguide and planar resonators, Dielectric resonators, loaded, unloaded, and external Q-factors, SPST and SPDT switches. (8 lectures)

Beam-forming network: Introduction to mmwave circuits: hybrid coupler, crossover, phase shifter, butler matrix, nolen matrix, Rotman lens. (5 lectures)

Millimeter wave antennas: Problem with traditional antennas, horn antenna, dielectric rod antenna, Leaky wave antenna, waveguide slot array, chain antenna array, on chip antennas, monopulse radar network, transmitarray, reflectarray, millimeterwave over the air (OTA) measurement testing: Total Radiated Power (TRP), Total Isotropic Sensitivity (TIS), Effective Isotropic Radiated Power (EIRP), Effective Isotropic Sensitivity (EIS). (10 lectures)

Packaging and interconnects: Challenges in packaging, design of interconnects at mm-wave frequencies, bondwire interconnections, ball-grid array. (3 lectures)

Millimeterwave Active circuits: mmwave CMOS circuits: LNA, Oscillator, VCO, Power Amplifier, Frequency Synthesizer, SoC for mmwave RADAR, FinFET (10 Lectures)

Case Studies: mmwave transciever for 5G, industrial radar sensor (2 lectures)

Textbook

1. Koul S. K., (1997), Millimeter Wave and Optical Dielectric Integrated Guides and Circuits, Wiley-Blackwell
2. Courtney D. Liu, B. Gaucher, U. Pfeiffer, and J. Grzyb, (2009), Advanced millimeter wave technologies, Wiley.
3. Hueber, G., & Niknejad, A. (Eds.). (2019). Millimeter-Wave Circuits for 5G and Radar (The Cambridge RF and Microwave Engineering Series). Cambridge: Cambridge University Press.

Self Learning Material

1. Mandal M. K., Millimeter-wave technology, NPTEL course material, Department of Electronics and Electrical Communication Engineering, IIT Kharagpur, https://nptel.ac.in/courses/117105139/
2. TI Training & Vedios, (2017), mmWave RADAR in ADAS Applications, https://training.ti.com/mmwave-radar-adas-applications

Preparatory Course Material

1. D. M. Pozar, (2011), Microwave Engineering, 4th Ed. New York, NY, USA: Wiley

Title	**Selected Topics In Sensors and IoT I**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	1–0–0 [1]
Offered for	M.Tech., PhD	Type	Elective
Prerequisite	Fundamentals of sensors		

Objectives

The Instructor will:

1. Expose the students to the latest upcoming fields in the area of sensors and IoT

Learning Outcomes

The students are expected to have the ability to:

1. Apply the knowledge of recent topics in the field of sensors and IoT to specific areas of research

Contents

The topic clouds for the course include some contemporary topics in sensors and IoT (but not restricted to) like Nanosensors, MEMS/NEMS sensors, biosensors modeling and design, industrial IoT. The topics may be further updated according to the instructor.

Textbook

Relevant Textbook and/or research papers to be announced by the instructor.

Self-Learning Material

Relevant Textbook and/or research papers to be announced by the instructor.

Preparatory Course Material

Relevant Textbook and/or research papers to be announced by the instructor.

Title	**Selected Topics In Sensors and IoT II**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–0 [2]
Offered for	M.Tech., PhD	Type	Elective
Prerequisite	Fundamentals of sensors		

Objectives

The Instructor will:

1. Expose the students to the latest upcoming fields in the area of sensors and IoT

Learning Outcomes

The students are expected to have the ability to:

1. Apply the knowledge of recent topics in the field of sensors and IoT to specific areas of research

Contents

The topic clouds for the course include some contemporary topics in sensors and IoT (but not restricted to) like Nanosensors, MEMS/NEMS sensors, biosensors modeling and design, industrial IoT. The topics may be further updated according to the instructor.

Textbook

Relevant Textbook and/or research papers to be announced by the instructor.

Self-Learning Material

Relevant Textbook and/or research papers to be announced by the instructor.

Preparatory Course Material

Relevant Textbook and/or research papers to be announced by the instructor.

Title	**Selected Topics In Sensors and IoT III**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech., PhD	Type	Elective
Prerequisite	Fundamentals of sensors		

Objectives

The Instructor will:

1. Expose the students to the latest upcoming fields in the area of sensors and IoT

Learning Outcomes

The students are expected to have the ability to:

1. Apply the knowledge of recent topics in the field of sensors and IoT to specific areas of research

Contents

The topic clouds for the course include some contemporary topics in sensors and IoT (but not restricted to) like Nanosensors, MEMS/NEMS sensors, biosensors modeling and design, industrial IoT. The topics may be further updated according to the instructor.

Textbook

Relevant Textbook and/or research papers to be announced by the instructor.

Self-Learning Material

Relevant Textbook and/or research papers to be announced by the instructor.

Preparatory Course Material

Relevant Textbook and/or research papers to be announced by the instructor.