Signals and Systems (GE)

Credits: Theory-03 **Theory Lectures: 45h**

Course Learning Objectives

- Understand mathematical description and representation of continuous and discrete time signals and systems.
- Develop input-output relationship for linear shift invariant system and understand the convolution operator for continuous and discrete time system.
- Understand and resolve the signals in frequency domain using Fourier series and Fourier transforms.
- Understand the limitations of Fourier transform and need for Laplace transform and develop the ability to analyze the system in s- domain.

Course Learning Outcomes

At the end of this course, Students will be able to

1. Represent various types of continuous-time and discrete-time signals and their convolution.
2. Understand concept of convolution, LTI systems and classify them based on their properties and determine the response of LTI system.
3. Determine Fourier series of continuous and discrete periodic signals.
4. Determine the Fourier and Laplace transformations of continuous time signals.

Prerequisite: Basic knowledge of electronic circuits.

L-T-P: 3-0-1

Syllabus Contents

Unit I: **(11 Lectures)**
Signals: Continuous and discrete time signals, time domain operations - Shifting, Scaling, and Inversion. Basic signals: Impulse, Unit step, Ramp, Exponential and Sinusoidal signals, Even and Odd signals, Periodic and Non-periodic signals. Time period of various periodic signals.
.
Unit II: **(11 Lectures)**
Systems: Continuous-time and discrete-time systems and their basic properties. Continuous and Discrete LTI systems and their Convolution property. Properties of LTI systems - Commutative, Distributive, Associative. LTI systems with and without memory, invariability, causality, stability, unit impulse response and unit step response.
Block diagram, Signal Flow Graph, structure for IIR and FIR systems form structures, Cascade structures.

Unit III: (12 Lectures)

Fourier Series: Fourier series representation of periodic continuous and discrete signals, Dirichlet conditions, Convergence of the Fourier series.

Fourier Transform: Fourier Transform of continuous time signals, Properties of Continuous-time Fourier transform, Convolution and multiplication Properties, Properties of Fourier transform and basic Fourier transform Pairs.

Unit IV: (11Lectures)

Laplace Transforms: Unilateral Laplace transform of continuous time signals, Region of Convergence, Inverse Laplace transform, properties of the Laplace transform, Laplace transform pairs.

References/Suggested Readings

1. V. Oppenheim, A. S. Wilsky and S. H. Nawab, Signals and Systems, Pearson Education (2007)
2. H. P. Hsu, Signals and Systems, Tata McGraw Hill (2007).
3. S. Haykin and B. V. Veen, Signals and Systems, John Wiley & Sons (2004).

Signals and Systems Lab
(Scilab/MATLAB/ OCTAVE/Other Mathematical Simulation software)

Credits: 01 **Lectures:30 hours**

Course Learning Outcomes of the Lab

At the end of this course, Students will be able to

1. Generate/plot various signals, there transformation and compute convolution.
2. Generate/plot Fourier series of periodic signals.
3. Compute Fourier transform
4. Learn the use of simulation tools and design skills.
5. Learn to work in groups and to develop Scilab/MATLAB/OCTAVE/ other mathematical simulation software simulations of various signals and systems.

Suggested list of Praticals

1. Plotting/generation of signals: continuous time.
2. Plotting/generation of signals: discrete time.
3. Time shifting and time scaling of signals.
4. Convolution of signals.
5. Fourier series representation of continuous time signals.
6. Fourier series representation of discrete time signals.
7. Computation of Fourier transform of continuous time signals.
8. Laplace transform of continuous time signals.

Semiconductor Devices (GE)

Credits: Theory 03 **Theory Lectures: 45 Hours**

Course Learning Objectives

- To understand the Physics of semiconductor devices
- To be able to plot and interpret the current voltage characteristics for basic semiconductor devices
- The student should be able to understand the behaviour, characteristics and applications of optoelectronic devices such as solar cell, LED, photodiode

Prerequisites: Fundamental concepts of physics taught at class XI and XII

UNIT 1 **(12 Lectures)**

Basic Concepts of Semiconductors: Energy Bands in Solids, Concept of Effective Mass, Direct and Indirect Bandgap Semiconductors, Density of States (Qualitative understanding) Carrier Concentration at Normal Equilibrium in Intrinsic Semiconductors and its Temperature Dependence, Derivation of Fermi Level for Intrinsic and Extrinsic Semiconductors and its Dependence on Temperature and Doping Concentration.

Carrier Transport Phenomena: Drift velocity, Mobility, Resistivity, Hall Effect, Conductivity, Diffusion Process, Einstein Relation, Current Density Equation, Carrier Injection, Generation and Recombination Processes (Qualitative concepts), Continuity Equation.

UNIT 2 **(12 Lectures)**

P-N Junction Diode: Space Charge at a Junction, Depletion Layer, Electrostatic Potential Difference at Thermal Equilibrium, Depletion Width and Depletion Capacitance of an Abrupt Junction and its application as a Varactor Diode**.**

Diode Equation and I-V Characteristics (Qualitative), Zener and Avalanche breakdown Mechanism. Working and applications of Zener diode.

Ohmic and Rectifying Contacts

UNIT 3 **(10 Lectures)**

Bipolar Junction Transistors (BJT): PNP and NPN Transistors, Energy Band Diagram of Transistor in Thermal Equilibrium, Emitter Efficiency, Base Transport Factor, Current Gain Relation between alpha and beta, Base-Width Modulation, Early Effect, Modes of operation Input and Output Characteristics of CB, CE and CC Configurations and their Applications.

UNIT 4 **(11 Lectures)**

Junction Field Effect Transistors: Channel Formation, Pinch-Off and Saturation Voltage, Input, Transfer and Output Characteristics.

MOSFET: NMOS, PMOS, Types of MOSFET, Circuit symbols, Working and Characteristic Curves of Depletion mode and Enhancement mode MOSFET (both N channel and P Channel), Complimentary MOS (CMOS) as an Inverter.

Optoelectronic Devices: LED, Photodiode, Solar cell, LDR, their Circuit Symbols, Characteristics and Applications.

References

1. S.M Sze Semiconductor Devices: Physics and Technology,2nd Edition, Wiley India Edition
2. Ben. G Streetman and S. Banerjee Solid State Electronic Devices, Pearson Education
3. Dennis Le Croissette, Transistors, Pearson Education.
4. Jacob Millman and Christos Halkias: Electronic Devices and Circuits, Tata McGraw-Hill Edition.
5. Kannan Kano, Semiconductor Devices, Pearson Education.

Semiconductor Devices Lab
(Hardware and Circuit Simulation Software)

Credits:01 **Lectures: 30h**

(Course Learning Outcomes)

At the end of this course, Students will be able to

CO1 Examine the characteristics of Semiconductor Devices

CO2 Perform experiments for studying the behaviour of semiconductor devices for circuit design applications

CO3 Calculate various device parameters values from their I-V Characteristics

CO4 Interpret the experimental data for better understanding of the device behaviour

Syllabus Contents

1. Study of the I-V Characteristics of Ordinary diode
2. Study of the I-V Characteristics of Zener diode
3. Study of the I-V Characteristics of Solar cell
4. Study of the I-V Characteristics of the CE configurations of BJT
5. Study of the I-V Characteristics of the CB configurations of BJT
6. Study of the I-V Characteristics of JFET
7. Study of Hall Effect.

Digital System Design using VHDL (GE)

Credits: Theory-03 **Total Hours: 45**

Course Learning Objectives

- To learn coding in hardware description language.
- Identify the basic language elements.
- Understand the HDL design flow and write codes in VHDL.
- To simulate and verify the code.

Course Learning Outcomes

At the end of this course, Students will be able to

CO1: To identify the basic structure of VHDL code.
CO2: Write a code to simulate and synthesize various combinational circuits.
CO3: Develop an understanding to simulate and verify the code.

Prerequisite: Basic Knowledge of Digital circuits and any programming language.

L-T-P: 3-0-1

Syllabus Contents

Unit 1: **(10 Lecutres)**
Introduction to VHDL: Design flow, Simulation and Synthesis tools, Translation of VHDL code into a circuit. Code Structure: Fundamental VHDL units, library declaration, Entity, Architecture, Package declaration.

Unit 2: **(12 Lectures)**
Basic Language Elements: Keywords, Identifiers, White Space Characters, Comments, Data object, class constant, variable, signal, file. Modes: In, Out, In-Out, Buffer. Data Types: Bit, Bit Vector, Boolean, Integer, Real. Data Operators: Assignment operator, Logical operators, Arithmetic operators, Relational operators, Shift operators, Concatenation operators.

Unit 3: **(12 Lectures)**
Concurrent code versus Sequential code, Data flow Modeling: Concurrent signal assignment statement, ,Conditional signal assignment statement, Selected signal assignment statement. Simple When statement ,Selected When Statement, Implementation of combinational circuits using concurrent codes e.g. adder , subtractor, decoder , multiplexer, code converter etc.

Unit 4: **(11 Lectures)**
Structural modeling: Component declaration, Component instantiation, Port map, Positional association, Named association. Hierarchical Design, Implementation of circuits using structural modelling e.g. full adder, Parallel adder /subtracter, ALU etc.

References:

1. A VHDL Primer, Jayaram Bhasker

2. Circuit Design and Simulation with VHDL, Volnei A. Pedroni, PHI learning private Ltd.

Digital System Design using VHDL Lab

Credits: Practical-01 **Total Hours: 30**

List of Practicals: (minimum 10 practicals are to be performed)

Write HDL code to simulate and verify

1. Basic and derived logic gates.
2. Half Adder and Full Adder.
3. Half Subtractor and Full Subtractor.
4. Tri-state buffer.
5. Multiplexer.
6. Demultiplexer.
7. Decoder.
8. Encoder.
9. 4 bit Parallel Adder.
10. Binary to Gray Code converter.
11. Gray to Binary Code Converter.
12. 2 bit Magnitude comparator.

VLSI: Technology and Design (GE)

Credits: Theory-03 **Theory Lectures: 45h**

Course Learning Objectives:

- The course deals with knowledge of materials required for VLSI technology.
- It deals with the BJT vs MOS Technology.
- Importance of MOS in VLSI.
- VLSI logic design using CMOS.

Course Learning Outcomes

At the end of this course, students will be able to

CO1: Summarize the developments in the field of Microelectronics Technologies.

CO2: Learn the VLSI technology basics.

CO3: Learn about the role of CMOS in VLSI Technology and Design

CO4: Understand the concept of implementation of various logic design using CMOS.

Prerequisites: Basic knowledge of semiconductor theory and digital circuits.

L-T-P: 3-0-1

Syllabus Contents

Unit 1 **(10 lectures)**

Introduction to VLSI Technology: Overview of VLSI and its applications; Semiconductor basics: Materials (Si, Binary Materials like GaN, GaAs).

Crystal growth techniques: Growth of bulk Silicon single crystals using Czochralski (CZ) technique, Doping while crystal growth (Distribution of dopants, Effective Segregation Coefficient), Float Zone (FZ) technique, GaAs bulk single crystal growth by Bridgman-Stockbarger technique.

Wafer Cleaning Technology: Basic Concepts, Wet cleaning, Dry cleaning

Unit 2 **(11 lectures)**

Semiconductor Devices: PN junction diode, BJT, MOS; MOS transistors: Basic operation and characteristics; VLSI technology basics (Diffusion/Ion Implantation for doping, Oxidation, Metallization, Packaging).

Unit 3 **(12 lectures)**

VLSI Design Methodology: Importance of MOS in VLSI Design(Characteristics as Power Consumption, Device density on a single Chip); MOS Structures (NMOS, PMOS, CMOS structures); various logic devices made from MOS (Registers, Memories (RAM & ROM). **VLSI design flow:** behavioral, structural, data flow methods; Device and gate-level design.

Unit 4 **(12 lectures)**

CMOS Logic Design (Approx. 12 hours): CMOS inverter and its characteristics; CMOS circuit layout considerations; Introduction to simulation and verification techniques (devices/circuits); Combinational logic using CMOS (AND, OR, NOT, NAND, NOR, XOR, half adder, full adder); Sequential logic using CMOS (Flip Flops, Counters, Registers).

References:

1. Gary S.May and S.M.Sze: Fundamentals of Semiconductor Fabrication, John Wiley & Sons (2004).
2. Douglas A Pucknell, Kamran Eshraghian: Basic VLSI design, PHI.
3. Weste and Harris: CMOS VLSI Design: Circuits and Systems Perspective, Addison-Wesley.
4. Kang and Lebelbigi: CMOS Digital IC Circuit Analysis and Design, McGraw Hill.

VLSI: Technolgy And Design

(Pspice/other Simulation Software)

Credits: 01 **Lectures: 30h**

Syllabus Content

1. To measure the resistivity of semiconductor crystal with temperature by four –probe method.
2. To determine the type (n or p) and mobility of semiconductor material using Hall effect.
3. CZ technique Simulation/Float zone technique Simulation
4. Oxidation process Simulation/Diffusion Process Simulation
5. To plot the (i) output characteristics & (ii) transfer characteristics of an n-channel and p-channel MOSFET.
6. To design and plot the static and dynamic characteristics of a digital CMOS inverter.
7. To design and plot the dynamic characteristics of 2-input NAND, NOR, XOR and XNOR logic gates using CMOS technology.
8. To prepare layout for given logic function and verify it with simulations.
9. To measure propagation delay of a given CMOS Inverter circuit.

Note: Visit to Research Lab/institutions to see the live demonstrations of the processes and preparation of a report.

Internet of Things (GE)

Credits: Theory-03+ Practical-01 **Theory Lectures: 45h**

Course Learning Objectives

This course describes the Internet of Things (IoT), technology used to build these kinds of devices, how they communicate, how they store data, and the kinds of distributed systems needed to support them. Broad objectives are:

1. To introduce the IoT terminology, technology and its applications
2. To introduce the concept of M2M (machine to machine) with necessary protocols
3. To introduce the Arduino / Raspberry Pi platform and Programming Language widely used in IoT applications
4. To Familiarize the protocols, design requirements, suitable algorithms, and the state-of-the-art cloud platforms.
5. To introduce the implementation of web-based services on IoT devices.

Course Learning Outcomes

At the end of this course, students will be able to
CO1: Understand fundamentals and applications of Internet of Things, its hardware and software components
CO2: Understand the methodologies and tools involved (device, data, cloud) in the design of IoT Systems
CO3: Understand interfacing, technological challenges faced by IoT sensors and communication modules, with a focus on wireless, energy, power and sensing modules
CO4: Understand the working principle of the state-of-the-art cloud platforms to meet the industrial requirement for remote monitoring of data and control IoT based system.

Prerequisite: Basic knowledge of digital circuits and idea about microprocessors/ microcontrollers.

L-T-P: 3-0-1

Syllabus Contents

UNIT 1: Introduction to IoT **(11 Lectures)**

Introduction to IoT: Definition and Characteristics of IoT, Architectural Overview, Design principles and needed capabilities.
Physical design of IoT: IoT protocols in Link Layer, Network/Internet Layer, Transport Layer, Application Layer, Basics of Networking.
Logical design of IoT: Functional blocks, Communication Models and APIs, IoT levels and deployment templates.
M2M and IoT Technology Fundamentals, Software defined networks (SDN), network function virtualization (NFV), Basics of IoT System Management with SNMP, NETCONF - YANG.

UNIT 2 : Communication Protocols and IoT Components : **(11 Lectures)**

Communication Protocols - MQTT, Bluetooth, CoAP, TCP.
Hardware Components: Transducers, Sensors, Actuators and I/O interfaces – Concept, Characteristic and Classification of Sensors (Position, Velocity, Force, Temperature and Humidity, Motion Detection, ADC, Light, Bluetooth, etc.)

UNIT 3: Hardware Components - (Arduino/RaspberryPi) (12 Lectures)

Raspberry Pi: Communication with devices through the pins of the Raspberry Pi, RPi. GPIO library, Basics of Python programming and Python Functions, General purpose IO Pins, Protocol Pins, applying digital voltages, and generating Pulse Width Modulated signals, Tkinter Python library, accessing pins through a graphic user interface.

OR

Arduino: Arduino board - main components, inputs, and outputs. Arduino Integrated Development Environment (IDE), Basics of C programming. Composition of an Arduino programs, Arduino tool chain, basic structure of a sketch, including the use of the setup() and loop() functions. Accessing the pins from a sketch for input and output

Arduino/Raspberry Pi compatible shields together with their libraries.

Software components- Programming API's (using Python/Node.js/Arduino). UART, Serial libraries for communication with the serial monitor for Arduino/Raspberry Pi

Interfacing sensors and actuators with Arduino/Raspberry Pi.

**** It is optional to choose either Arduino or Raspberry Pi environment**

UNIT 4: IoT Applications (11 Lectures)

IoT Physical Devices and Endpoints, Domain specific IoTs, IoT Physical Servers and Cloud Offering Cloud Computing: Characteristics, Introduction to Cloud Service models (SaaS, PaaS, IaaS, XaaS etc.) Deployment models, Cloud storage APIs, IoT-Cloud convergence, Communication Enablers Webservices – Web server for IoT, Python-Web frameworks, RESTful Web API, ThingSpeak API, MQTT.

IoT Application Development - Solution framework for IoT applications- Implementation of Device integration, Data acquisition and integration, Device Data Storage - Unstructured data storage on cloud/local server, Authentication, authorization of devices.

IoT security, Basics of symmetric and non-symmetric encryption standards, IoT Case Studies.

References:

1. "A Internet of Things - A Hands-on Approach", Arshdeep Bahga and Vijay Madisetti, Universities Press, 2015, ISBN: 9788173719547
2. "Designing Internet of Things", Adrian McEwen and Hakim Cassimally, John Wiley and Sons, 2014.
3. "Introduction to Internet of Things: A practical Approach", Dr. SRN Reddy, Rachit Thukral and Manasi Mishra, ETI Labs
4. "From Machine-to-Machine to the Internet of Things: Introduction to a New Age of Intelligence", Jan Holler, Vlasios Tsiatsis, Catherine Mulligan, Stefan Avesand, Stamatis Karnouskos, David Boyle, 1st Edition, Academic Press, 2014.
5. "Exploring Arduino: Tools and Techniques for Engineering Wizardr", Jeremy Blum, Wiley & Sons, 2013, ISBN : 9781118549360
6. "Getting Started with Raspberry Pi", Matt Richardson & Shawn Wallace, O'Reilly (SPD), 2014, ISBN: 9789350239759.
7. "Raspberry Pi Cookbook, Software and Hardware Problems and solutions", Simon Monk, O'Reilly (SPD), 2016, ISBN 7989352133895

Internet of Things Lab

Credits: 01 **Lectures: 30h**

Course Learning Outcomes

At the end of this course, students will be able to

CO1: Execute programs on Arduino/Rasberry Pi boards.

CO2: Interface various I/O devices, sensors & actuators and implement them in various practical applications

CO3: Use various communication modules and protocols for data communication between devices, sensors and actuators for wired as well as wireless applications

CO4: Implement Wireless Control of Remote Devices and manage data through cloud based applications.

Syllabus Contents

1. Connect an LED and a Switch/Digital Sensor (IR/LDR, etc) and control the LED with the Switch/Digital Sensor.
2. To interface DHT11 sensor with Arduino/Raspberry Pi and write a program to print temperature and humidity readings.
3. To interface Bluetooth with Arduino/Raspberry Pi and write a program to send sensor (analog, digital) data to smartphone using Bluetooth.
4. To interface Bluetooth with Arduino/Raspberry Pi and write a program to turn on various options of RGB LED for different data received from smartphone using Bluetooth.
5. Create a traffic light signal with three colored lights (Red, Orange and Green) with an interval of 5-2-10 seconds.
6. Create an application that has three LEDs (Red, Green and white). The LEDs should follow the cycle (All Off, Red On, Green On, White On) for each clap (use sound sensor).
7. Write a program on Arduino/Raspberry Pi to upload/retrieve temperature and humidity data using ThingSpeak cloud.
8. Write a program on Arduino/Raspberry Pi to publish/subscribe temperature data using MQTT broker.
9. Write a program to create TCP server on Arduino/Raspberry Pi and respond with humidity data to TCP client when requested.
10. Create a web application as a project for any of the IoT Case Studies based on Smart Environment, Industrial automation, Transportation, Agriculture, Healthcare, Home Automation with functionalities to get input and send output.

Indicative Course Teaching-

Learning Processes and Assessment Methods are listed in section 7.3 and 7.4 respectively along with Table 1 on Suggestive Learning and Evaluation Strategies.

Digital Signal Processing (GE)

Credits: Theory-03 **Theory Lectures: 45h**

Course Learning Objectives

The course aims to familiarize students with contemporary digital processing techniques essential across diverse application domains. Key focus areas include fundamental concepts pertaining to discrete-time signals and systems, alongside the analysis of signals in both time and frequency domains utilizing Fourier and Z transforms. Additionally, students will be introduced to the methodologies involved in the architecture and design of digital filters.

Course Learning Outcomes

At the end of this course, Students will be able to

CO1: Illustrate digital signals, systems and their significance
CO2: Master fundamental concepts of discrete-time signals, linear time-invariant systems, and transform techniques such as Z-transform and Fourier transform.
CO3: Analyze linear time-invariant systems proficiently using Fourier and Z-transform methods.
CO4: Understand and apply design techniques for Digital FIR and IIR filters, including direct methods and analog-to-digital filter conversion.
CO5: Utilize DFT for frequency analysis and implement FFT algorithms for efficient computation in signal processing applications.

Prerequisite: Basic knowledge of electronic circuits, signals and their representation, fourier series and Laplace transforms.

L-T-P: 3-0-1

Syllabus Contents

Unit I: **(10 Lectures)**
Discrete Time Sequences and Systems: Applications of Digital Signal Processing, Review of continuous time and discrete time signals and systems**,** Introduction to discrete time sequences, Properties of DT systems. LTI systems and their properties
Fourier Transform: Frequency domain representation of signals and their interpretations, Interchangeable relationships between time and frequency domains Fourier Transform, Properties of Fourier Transform, Inverse Fourier Transform, Transfer Function of LSI systems.

Unit II: **(12 Lectures)**
Z-Transform: Definition, Unilateral Z- transform, Region of Convergence and its properties, Properties of Z-Transform, Initial and final value theorem. Z-transform and its properties.
Inverse Z Transform: Long division, Partial fraction, and Residual methods. Parseval's Theorem and Applications.

System Function: Linear constant coefficient difference equation, Representation and analysis of Discrete Time Systems, Stability, Causality, Realisation of Digital Linear Systems: Block diagram, Signal Flow Graph, structure for IIR and FIR systems form structures, Cascade structures

Unit III: **(12 Lectures)**

Discrete Fourier Transform: DFT assumptions and Inverse DFT, magnitude and phase representation Matrix relations, relationship with Fourier Transform, Linear and circular convolution, properties of DFT, Computation of DFT. FFT Algorithms- Decimation in time FFT. Decimation in frequency FFT, FFT using radix 2 FFT — Butterfly structure, Concept of Gibb's phenomenon and word length effects.

Unit IV: **(12Lectures)**

Digital Filters: Characteristics of commonly used Analog filters, Comparison of Analog and Digital Filters, Types of Digital Filters: FIR and IIR. FIR Filter realization using Windowing method, Design of IIR Filters by Approximation of Derivates, Impulse Invariant Method, Bilinear Transformation, Analog Butterworth Filter Design, and Frequency transformations.

References/Suggested Readings

1. A.V. Oppenheim and Schafer, Discrete Time Signal Processing, Prentice Hall, 1999.
2. John G. Proakis and D.G. Manolakis, Digital Signal Processing: Principles, Algorithms and Applications, Prentice Hall, 2007.
3. S. Salivahanan, Digital Signal Processing, McGraw Hill, 2015.
4. Tarun Kumar Rawat, Digital Signal Processing, Oxford University Press, 2015.
5. Monson Hayes, Digital Signal Processing: Second Edition, Schaum,s Outline Series
6. Sanjit K Mitra "Digital Signal Processing" TMH

Digital Signal Processing Lab

Course Learning Outcomes of the Lab

At the end of this course, Students will be able to

CO1: Utilize software tools to simulate, synthesize, and manipulate signals, enhancing practical understanding and application of signal processing concepts.

CO2: Employ transform techniques to represent signals and systems effectively in both time and frequency domains, enabling comprehensive analysis and interpretation.

CO3: Engage in simulation and design processes for Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters, fostering hands-on experience and proficiency in digital filter design methodologies.

(Scilab/MATLAB/Python other Mathematical Simulation software)

1. Write a program to generate discrete time Unit Impulse, Unit Step, Unit ramp and Sinusoidal sequences.
2. Write a program for shifting and scaling Discrete time systems.
3. Write a program to find the Fourier Transform of a sequence.
4. Write a program to find the pole-zero plot of a function.
5. Write a program to find a function's Z transform and inverse Z transform.
6. Write a program to find the circular convolution of two sequences.
7. Write a program to find the DFT of a sequence using the direct method.
8. Write a program to find the DFT of a sequence using FFT.
9. Magnitude Response of Low Pass Filter and High Pass Filter.
10. Design FIR Filter using Window Function.
11. Convert Analog Filter to Digital IIR Filter.

Process Control Systems (GE)

Credits: Theory-03 **Theory Lectures: 45h**

Course Learning Objectives

This course introduces the student to the fundamental understanding of process control, basic principles of various manufacturing processes, mathematical modeling and analysis of open loop and closed loop control systems in terms of electrical equivalent circuits. Student would be in position to explain the nature of stability of systems using different criteria and plots.

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Course Learning Outcomes

At the end of this course, Students will be able to

CO1 Analyze the concepts of open and closed loop control systems
CO2 Develop the mathematical model of a physical system
CO3 Analyze the stability of control systems with the help of different criteria and plots.
CO4 Identify the needs of different type of controllers.
CO5 Understand the need of process control, basic principles of various manufacturing processes and apply engineering knowledge to do problem analysis in process control

Prerequisites: Basic knowledge of analog and digital circuits and different types of signals.

L-T-P: 3-0-1

Syllabus Contents

Unit I: Introduction to Process Control **(11 lectures)**

Process variables, degree of freedom, industrial measurement systems, different types of industrial variables and measurement systems elements, sensors and transducers for different industrial variables like pressure, torque, speed, temperature etc., sensor principles, examples of sensors, sensor scaling, Industrial signal conditioning systems, Amplifiers, Filters, A/D converters for industrial measurements systems, review of general industrial instruments, I/P and P/I converters, pneumatic and electric actuators.

Unit II: Introduction to Control Systems **(11 lectures)**

Overview of Laplace Transformation, Classification of systems (Definitions only): Linear and Nonlinear systems, Time invariant and Time varying system, Continuous time and Discrete time system, Dynamic and Static system, SISO and MIMO, Open loop and Closed loop control systems, Transfer functions, Mathematical modelling of Physical systems (Electrical, Mechanical), block diagram representation & signal flow graph, Mason's Gain Formula, Effect of feedback on parameter variations.

Unit III: Time Domain Analysis **(12 lectures)**

Test input signals for transient Analysis, transient response of first, second and higher order system for different test input signals, Time domain performance parameters of second order System, Steady state errors and Static error constants. Concept of Stability: Effect of location of poles on stability, Asymptotic stability and Conditional stability, Routh-Hurwitz criterion, Concept and applications of PI, PD and PID controllers.

Unit IV: Frequency Domain Analysis (11 lectures)

Advantages of frequency domain analysis, Frequency domain specifications, Correlation between time and frequency response, Logarithmic plots (Bode Plots), Gain and Phase margins, Nyquist stability criterion. Compensation Techniques: Concept of compensation techniques, Lag, Lead and Lag-Lead networks.

References/Suggested Readings

1. J. Nagrath & M. Gopal, Control System Engineering, New Age International, 2021
2. B S Manke, Linear Control Systems, Khanna Publications
3. A. Anand Kumar, Control Systems, PHI, 2014
4. K. Ogata, Modern Control Engineering, Pearson, 2015
5. B. C. Kuo, Automatic Control Systems, Wiley, 2014
6. Joseph J. DiStefano, Allen Stubberud, Ivan J. Williams, Control Systems (Schaum's Outline Series), Tata McGraw Hill
7. C.D. Johnson, Process Control Instrumentation Technology, Pearson
8. Thomas E Marlin, Process Control: Designing Processes and Control Systems for Dynamic Performance, Tata McGraw Hill.

Process Control Systems Lab

(Hardware and Scilab/MATLAB/Other Mathematical Simulation software)

Credits: 01 **Lectures: 30h**

Course Learning Outcomes

At the end of this course, Students will be able to

CO1 Perform experiments involving concepts of control systems
CO2 Understand, interpret and implement tuning of the controllers using various methods and study about digital controllers
CO3 Design experiments for controlling devices
CO4 Study behavior of systems

Syllabus Contents

1. To study response of systems for various standard test input signals.
2. To study an open loop system.
3. To study a closed loop system.
4. To study steady state error of a system.
5. To study I/P and P/I systems.
6. To study time and frequency domain specifications of a control system.
7. To plot Bode and Nyquist plots and determine stability.
8. To study the Routh Hurwitz criterion of a system.
9. To study the effect of PI, PD and PID controller on closed loop systems.
10. To design a sensor/transducer based control system.
11. Report making after an Industrial visit to see process control systems working.

Communication Systems (GE)

Credits: Theory-03 **Theory Lectures: 45h**

Course Learning Objectives

- To introduce various continuous wave modulation techniques used in communication systems and analyse their comparative performance.
- To understand basics of pulse analog and digital modulation techniques.

Course Learning Outcomes

At the end of this course, Students will be able to

CO1: Understand the fundamentals of a communication system

CO2: Analyse various continuous wave modulation schemes

CO3: Distinguish between various CW modulation schemes

CO4: Understand the principles of sampling and pulse communication systems

Prerequisite: Basic knowlege of electronic circuits

L-T-P: 3-0-1

Syllabus Contents

Unit-I **(10 Lectures)**

Introduction: Block diagram of an electronic communication system, Electromagnetic spectrum- band designations and applications, Need for modulation, Concept of channels and base-band signals.

Basic introduction to external and internal noise, Signal to noise ratio.

Unit-II ` **(12 Lectures)**

Amplitude Modulation: Modulation index and frequency spectrum, Power Relations in AM. Generation of AM using diode balanced modulator, Demodulation of AM using envelope detector, Concept of double side band suppressed carrier, Single side band suppressed carrier, pilot carrier modulation, Vestigial side band modulation.

Block diagrams of AM transmitter and receiver.

Unit-III **(11 Lectures)**

Angle modulation: Frequency and phase modulation, Modulation index and frequency spectrum, Equivalence between FM and PM (qualitative), Generation of FM using direct and indirect methods (block diagrams), Demodulation of FM using PLL. Concept of pre-emphasis and de-emphasis. Comparison between AM, FM and PM.

Block diagrams of FM transmitter and receiver.

Unit -IV **(12 Lectures)**

Pulse Analog Modulation: Sampling theorem, Aliasing and aperture Effect, Pulse amplitude modulation, Pulse width modulation, Pulse position modulation, Generation and detection techniques for PAM, PWM and PPM.

Pulse Code Modulation: Need for digital transmission, Block diagram of a PCM system, Uniform and non-uniform quantization, Quantization noise, Line coding.

References/Suggested Reading:

1. Electronic Communication Systems- G. Kennedy and B. Davis.
2. Principles of Electronic Communication Systems- H. Taub and D. Schilling.
3. Electronic Communication Systems- W. Tomasi.
4. Principles of Electronic Communication Systems- L. E. Frenzel
5. Communication Systems (Analog and Digital)- R. P. Singh and S. D. Sapre

Communication Systems Lab

Credits: 01 **Lectures: 30h**

Course Learning Outcomes

At the end of this course, Students will be able to

CO1 Understand CW modulation methods

CO2 Demodulate CW modulated waves

CO3 Understand Pulse analog and digital modulation techniques

CO4 Simulate various modulation techniques

Syllabus Contents

The practical can be performed on hardware or any simulation software.

1. Study of Amplitude Modulation.
2. Study of Frequency Modulation.
3. Study of AM Demodulation
4. Study of FM Demodulation
5. Study of Pulse Amplitude Modulation
6. Study of Pulse Width Modulation
7. Study of Pulse Position Modulation.
8. Study of Pulse Code Modulation

Embedded Systems (GE)

Credits: Theory-03 **Theory Lectures:45**

Course Learning Objectives

The course is designed to make students familiar with principles, features, classification, architectures, and design issues involved in embedded system. The selection criteria for choosing microcontroller based on system requirement in embedded systems is also discussed. Interrupts and interfacing concepts are included. A balance between hardware and software exposure is maintained.

Course Learning Outcomes

At the end of this course, students will be able to:

CO1 Learn the fundamental concepts related to embedded systems and architecture of microcontrollers.
CO2 Familiarize with Instruction Set and assembly language.
CO3 Understand the interrupts and interfacing concepts for common applications like general I/O, Timer and Counter.
CO4 Demonstrate knowledge of the development tools for a microcontroller and write assembly language code according to specifications and task.

Prerequisites: Basic knowledge of digital circuits, idea about microprocessors

L-T-P: 3-0-1

Syllabus Contents

Unit – 1 **(11 Lectures)**

Introduction to Embedded system: Embedded systems features, Categories of Embedded System: Standalone, Real Time, Networked, Mobile devices, Embedded system architecture Hardware architecture, processors, memory EPROM, EEPROM, FLASH, SRAM DRAM FRAM (qualitative idea of read write access times and board space), Ready to use Embedded design platforms (Arduino, Raspberry Pi), Use of IoT and machine learning in Embedded Systems.

Unit 2 **(11 Lectures)**

AVR Microcontroller: Overview of Harvard architecture and Von Neumann architecture, RISC and CISC microcontrollers. Introduction to ATMega32 AVR RISC microcontroller, Criteria for choosing a microcontroller, architecture overview, Status Register, General Purpose Register file, reset sources (Power-on, Brownout detector & Watchdog Timer)

Unit –3 **(11 Lectures)**

Instruction Set: Addressing Modes, Data Transfer Instructions, Arithmetic and Logic Instructions, Shift and Rotate instructions, Branch Instructions, Bit manipulation and Bit-test Instructions, MCU Control Instructions.
Assembly language.

Unit – 4 **(12 Lectures)**

Peripheral Interfacing: Input/Output Ports, configuring I/O ports, reading and writing data to I/O ports, Introduction to Interrupts, interrupt vector address and priority, ISR, External Interrupts, Introduction to Timers, Timer 0 modes of operation, Universal Synchronous and Asynchronous Serial Receiver and Transmitter (USART).

References

1. AVR Microcontroller and Embedded Systems: Using Assembly and C by Muhammad Ali Mazidi, Sarmad Naimi, Sepehr Naimi, PHI ,2013
2. Embedded system Design - Frank Vahid and Tony Givargis, John Wiley, 2002
3. Programming and Customizing the AVR Microcontroller by D. V.Gadre, McGraw-Hill ,2000
4. Atmel AVR Microcontroller Primer: Programming and Interfacing by Steven F. Barrett, Daniel J. Pack, Morgan & Claypool Publishers ,2012
5. AVR Microcontroller Datasheet.

Embedded Systems Lab

SOFTWARE REQUIRED: AVR STUDIO/similar IDE

Credits:01 **Practical Lectures:30**

Course Learning Outcomes

At the end of this course, students will be able to:

CO1 Program microcontroller for common applications like general I/O Port, data transfer, counter.

CO2 Use various peripherals on the microcontroller to implement systems, interrupts driven I/O and modes of timer/ counter.

CO3 Prepare the technical report on the experiments carried.

Syllabus Contents

1. Write a program to flash LED at an observable rate.
2. Write a program to flash LED at an increasing rate till it appears to be always ON.
3. Write a program to generate random numbers using LFSR(Linear feedback Shift Register).
4. Write a program to get data from Port A and Port B and perform arithmetic and logical operations. Display the result on output device.
5. Write a program to read the status of pin 0 of port B and if it is High then send FFH on port D else AAH on port D.
6. Write a program to generate a pulse with different duty cycles on bit 0 of Port D using timer.
7. Write a program to implement a decimal counter and display it on an output device.
8. Write a program to generate square wave on Port D using timer simultaneously transfer the contents from Port B to Port C

Neural Networks (GE)

Credits: Theory-03+ Practical-01 **Theory Lectures: 45h**

Course Learning Objectives

- To realize the significance of Artificial Intelligence in today"s era
- To study neural networks and become able to design neural network based algorithms
- To study fuzzy logic and use it as an alternative tool for modelling.
- To study genetic algorithms and learn about optimizing solutions using genetic algorithms
- To be able to work with imprecise and uncertain solution data for solving problems.

Course Learning Outcomes

At the end of this course, students will be able to

CO1 Realize the significance of Artificial Intelligence and basic Neural Networks
CO2 Learn the neural network algorithms, modelling using optimizing solutions
CO3 Apply the knowledge of Hyrid Systems
CO4 Work with imprecise and uncertain solution data for solving problems

Prerequisite: Basic knowledge about the principles of artificial intelligence and machine learning

L-T-P: 3-0-1

Syllabus Contents

Unit-1 **(9 Lectures)**

Basics of Artificial Intelligence System: Neural Network, Fuzzy Logic, Genetic Algorithm, Human intelligence vs Machine intelligence.

Fundamentals of Neural Networks: Definition of Neural Network, Model of Artificial Neuron, Neural Networks as Directed Graphs, Learning rules and various activation function.

Unit-2 **(12 Lectures)**

Neural Network Architecture: Mathematical Models of Neurons, Artificial neuron model Error Correction Learning, Learning Paradigms-Supervised, Unsupervised and Reinforcement Learning, ANN training algorithms- perceptron, training rules, Single Layer Feed-forward networks, Multilayer Feed-forward networks.

Unit-3 **(12 Lectures)**

Single Layer Perceptrons: Adaptive Filtering Problem, Unconstrained Organization Techniques, Linear Least Square Filters, Least Mean Square Algorithm, Learning Curves, Learning Rate Annealing Techniques, Perceptron –Convergence Theorem

Multilayer Perceptron: Back Propagation Algorithm XOR Problem, Heuristics, Output Representation and Decision Rule

Unit-4 **(12 Lectures)**

Feedback Neural Networks: Pattern storage and retrieval, Hopfield Model, Boltzmann Machine, Recurrent Neural Networks.

Fuzzy Logic and Genetic Algorithm: Introduction to Fuzzy Logic, Overview of Fuzzy Sets and Membership.

References:

1. NEURAL NETWORK by Simon Haykin, Pearson
2. NP Padhy,“Artificial Intelligence and Intelligent Systems”, Oxford University Press
3. Rajasekaran S. and Pai G.A.V., “Neural Networks, Fuzzy Logic and Genetic Algorithm Synthesis and applications”, PHI New Delhi.
4. Lin C. and Lee G., “Neural Fuzzy Systems”, Prentice Hall International Inc.
5. Goldberg D.E. “Genetic Algorithms in Search Optimization & Machine Learning”, Addition Wesley Co., New York.
6. Kosko B., “Neural Networks & Fuzzy Systems A dynamical systems approach to machine intelligence”, Prentice Hall of India.
7. T. Terano K Asai and M. Sugeno, “Fuzzy System Theory and its applications”, Academic Press

Neural Networks Lab

Course Learning Outcomes

At the end of this course, students will be able to

CO1 Design and train neural networks for pattern recognition problems
CO2 Design and train neural networks for classification and association problems
CO3 Design fuzzy logic based systems for real time applications

Syllabus Contents

1. Create a Perceptron with appropriate number of inputs and outputs. Train it using fixed increment learning algorithm until no change in weights is required.
2. Implementation of Unsupervised Learning Algorithm.
3. Implementation of Perceptron Learning model.
4. Write a program to implement Artificial Neural Network with and without back propagation.
5. Write a program to implement Logic Gates.
6. Pattern Recognition using Hopfield Network.
7. Implementation of Fuzzy Operations.
8. Implementation of Fuzzy Relations (Max-min Composition).

ROBOTICS (GE)

Credits:Theory-03 **Theory Lectures: 45h**

Course Learning Objectives

This course helps student to understand the fundamentals of robotics and their applications. They should be able to use various sensors and design an automated system which works depending on the various external environmental conditions. Student would be in a position to make rudimentary robot which is capable of moving along a predetermined path, follow a drawn line and other more equivalent applications.

Course Learning Outcomes

At the end of this course, Students will be able to

CO1 Familiarize with concept of robotics and its applications to various industries.

CO2 Familiarization with the programming environments used in robotics applications.

CO3 Understand the working of sensors, actuators and other components used in design and implementation of robot.

CO4 Designing timer/counter circuits and displays their out puts using LCD and other indicator devices.

CO5 Understand the communication standards and their uses in interfacing.

Prerequisite: Basic knowledge of analog and digital circuits, any programming language

L-T-P: 3-0-1

Syllabus Contents

Unit I: Introduction **(11 Lectures)**

Robots, Robotics (Definition only) ; types of Robots , components of robot , Robot degrees of freedom, Robot joints , Robot coordinates, Robot reference frames, Robot characteristics : payload, reach, precision, repeatability; Laws of Robotics, Introduction to Computer Vision and Pattern Recognition , Signal conditioning and Industrial Applications of robots.

Unit II : Robot programming and Programming Environments **(11 Lectures)**

Robot Programming modes: physical set up, Teach mode, Continuous Walk through mode and software mode, Integrated Development Environment (IDE) for AVR microcontrollers, free IDEs like AVR Studio, WIN AVR. Installing and configuring for Robot programming, In System Programmer (ISP),loading programmes on Robot

Unit III: Actuators and Sensors **(12 Lectures)**

Actuators: Characteristics of actuating systems**,** comparison of actuating systems (Hydraulic, Electric and Pneumatic), DC Motors ,Gearing and Efficiency, Servo Motors, Stepper motors, Motor Control and its implementations, Grippers (types only)

Sensors: White line sensors , IR range sensor of different range, Analog IR proximity sensors, Analog directional light intensity sensors, Position encoders, Servo mounted sensor pod/Camera

Pod, Wireless colour camera, Ultrasound scanner, Gyroscope and Accelerometer, Magnetometer, GPS receiver, Battery voltage sensing, Current Sensing
Indicators : LEDs and Buzzer

Unit IV: Robot control and Communication Technology (11 Lectures)
PWM generation and its applications in motor velocity control, servo control ,motor position control and event scheduling
Communication Technology : Wired RS232 (serial) Communication, Wireless Zigbee Communication, USB Communication, Simplex infrared Communication (IR remote to robot), LCD interfacing .

References/Suggested Readings:

1. Saha,S.K., Introduction to Robotics,2nd Edition, McGraw-Hill Education, New Delhi, 2014
2. R.K. Mittal,I.J. Nagrath,–Robotics&Control‖,Tata McGraw&Hills, 2005.
3. Robotic Engineering – An Integrated Approach by Richard D Klafter, Thomas A. Chmielewski and Michael Negin, Prentice Hall India (1989)
4. Saeed B. Niku, Introduction to Robotics , Analysis , systems and Applications , PHI(2007)

Robotics Lab

Credits: 01 **Lectures: 30h**

Course Learning Outcomes

At the end of this course, Students will be able to

CO1 Understand the fundamentals of Robotics and its components
CO2 Design the software and Hardware for day to day / long term applications.
CO3 Identify robots and its peripherals for satisfactory operation and control of robots for industrial and non-industrial applications.

Syllabus Contents

1. Interfacing experiment using available hardware like LCD, LED, Buzzer, Motors.
2. Read IR proximity sensor to determine if there is some object nearby and thus Control the motion of robot using IR sensors.
3. Control a robot using LDR/ laser
4. Simple Motion Control(programming the robot to move forward, backward, left and right)
5. Line following Robot (programming the robot to move along a define path, white line or black line)
6. Obstacle Detection (programming the robot for obstacle detection)
7. Project work

Nanoelectronics (GE)

Credits: Theory -03 **Theory Lectures: 45h**

Course Learning Objectives

The syllabus includes the basic concepts and principles to categories and understand nanomaterial. Various nanomaterial synthesis/growth methods and characterizations techniques are discussed to explore the field in detail. The effect of dimensional confinement of charge carries on the electrical, optical and structural properties are discussed. Interesting experiments which shape this filed are introduced. The important applications areas of nanomaterials are introduced.

Course Learning Outcomes

At the end of this course, students will be able to

CO1 Describe the principles of nanoelectronics and the processes involved in making nano components and material.

CO2 Explain the advantages of the nanomaterials and appropriate use in solving practical problems.

CO3 Explain the various aspects of nano-technology and the processes involved in making nano components and material.

CO4 Differentiate between various nanomaterials synthesis processes.

Prerequisite: Basic knowledge of the semiconductor theory

L-T-P: 3-0-1

Syllabus Contents

Unit-1 **(12 Lectures)**

Introduction: Definition of Nano-Science and Nano Technology, Applications of Nano-Technology.

Introduction to Physics of Solid State: Size dependence of properties, bonding in atoms and giant molecular solids, Electronic conduction, Systems confined to one, two or three dimension and their effect on property

Introduction to Quantum Theory for Nano Science: Time dependent and time independent Schrodinger wave equations. Particle in a box, Potential step: Reflection and tunneling (Quantum leak). Penetration of Barrier, Electron trapped in 2D plane (Nano sheet), Quantum confinement effectin nanomaterials.

Quantum Wells, Wires and Dots: Preparation of Quantum Nanostructure; Size and Dimensionality effect, Fermi gas; Potential wells; Partial confinement; Excitons; Single electron Tunneling, Infrared detectors; Quantum dot laser Superconductivity.

Unit-2 **(11 Lectures)**

Growth Techniques of Nanomaterials: Synthetic aspects: bottom up and top down approaches, Lithograpahic and Nonlithograpahic techniques, Sputtering and film deposition in glow discharge, DC sputtering technique (p-$CuAlO_2$ deposition). Thermal evaporation technique, E-beam evaporation, Chemical Vapour deposition(CVD), Synthesis of carbon nano-fibres and multi-walled carbon nanotubes, Pulsed Laser Deposition, Molecular beam Epitaxy, Sol-Gel Technique (No chemistry required), Synthesis of nanowires/rods, Electro deposition, Chemical bath deposition, Ion beam deposition system, Vapor-Liquid–Solid (VLS) method of nanowire.

Unit-3 **(12 Lectures)**

Methods of Measuring Properties and Characterization techniques: Microscopy: Scanning Probe Microscopy (SPM), Atomic Force Microscopy (AFM), Field Ion Microscopy, Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) including energy dispersive X-ray (EDX) analysis, Infra-red and Raman Spectroscopy, X-ray Spectroscopy, Magnetic resonance, Optical and Vibrational Spectroscopy, Characterization and application like biopolymer tagging and light emitting semiconductor quantum dots.

Unit-4 **(10 Lectures)**

Carbon nanotubes, nano cuboids, graphene, carbon quantum dots: Fabrication, structure, electrical, mechanical, and vibrational properties and applications. Use of nano particles for biological application, drug delivery and bio-imaging, Impact of nanotechnology on the environment.

References

1. Nanoscale Science and Technology, Robert W. Kelsall, Ian W. Hamley and Mark Geoghegan, John Wiley & Sons, Ltd., UK, 2005.
2. Nanomaterials: synthesis, properties and applications, Institute of Physics, 1998.
3. Introduction to Nanotechnology, Charles P. Poole Jr and Frank J. Owens, Wiley Interscience, 2003.
4. Electron Microscopy and analysis, 2nd ed. Taylor and Francis, 2000.
5. Bio-Inspired Nanomaterials and Nanotechnology, Edited by Yong Zhou, Nova Publishers.
6. Quantum dot heterostructures, Wiley, 1999.
7. Modern magnetic materials: principles and applications, John Wiley & Sons, 2000.
8. Nano: The Essentials: Understanding Nanoscience and Nanotecnology, T.Pradeep, Tata McGraw-Hill Publishing Company Limited, New Delhi, 2008.
9. Nanobiotechnology, concepts, applications and perspectives, Wiley-VCH, 2004.

Nanoelectronics Lab

Credit Practical : 01 **Practical Lectures : 30h**

Course Learning Outcomes

At the end of this course, students will be able to

CO1 Choose appropriate technique for the synthesis of nanomaterials based on its type and application

CO2 Calculate the material parameters of nanomaterials using suitable characterization techniques.

CO3 Visit to Research laboratories/USIC and use advanced tools/techniques for synthesis and characterization of nanomaterials.

CO4 Prepare a technical reports of the experiments carried out.

Suggested List of Practicals (any 6 from the list, Practical no. 10 should preferably be included in the list)

1. Synthesis of at least two different sizes of Nickel Oxide/ Copper Oxide/ Zinc Oxide Nano Particles Using Sol- Gel Method
2. Polymer synthesis by suspension method / emulsion method
3. B-H loop of nanomaterials.
4. Magneto resistance of thin films and nanocomposite, I-V characteristics and transientresponse.
5. Particle size determination by X-ray diffraction (XRD) and XRD analysis of the given XRD spectra
6. Determination of the particle size of the given materials using He-Ne LASER.
7. Selective area electron diffraction: Software based structural analysis based on TEM based experimental data from published literature. (Note: Later experiment may be performed in the lab based on availability of TEM facility).
8. Surface area and pore volume measurements of nanoparticles (a standard sample and a new sample (if available)).
9. Spectroscopic characterization of metallic, semiconducting and insulating nanoparticles.
10. Visit to Research Lab/institutions to see the live demonstrations of synthesis and characterization of the processes.