Department of Electronics and Communication Engineering
Faculty of Technology
University of Delhi

(Course Structure and Curriculum of B.Tech. (ECE) Fourth Year)

Faculty of Technology
University of Delhi

Detailed Course Structure and Curriculum of B.Tech. (ECE) Fourth Year

Department of Electronics and Communication Engineering
Faculty of Technology
University of Delhi

Course Structure of B. Tech (ECE) Fourth Year
Fourth Year

Semester – VII

S. No.	Course Domain	Course Title	Credits*			Total Credits
			L	T	P	
1.	DSC-19	Optical and Wireless Communication	3	0	1	4
2.	DSE-5	Select a course from the specified list of DSE-5				4
3.	DSE-6/GE-7	Select a course from the specified list of DSE-6/GE-7				4
4.	DSE-7/GE-8	Select a course from the specified list of DSE-7/GE-8				4
5.	Dissertation on Major or Dissertation on Minor / Specialisation or Academic Project / Entrepreneurship					6
Total Credits						22

Semester – VIII

S. No.	Course Domain	Course Title	Credits*			Total Credits
			L	T	P	
1.	DSC-20	RF and Microwave Engineering	3	0	1	4
2.	DSE-8	Select a course from the specified list of DSE-8				4
3.	DSE-9/GE-9	Select a course from the specified list of DSE-9/GE-9				4
4.	DSE-10/GE-10	Select a course from the specified list of DSE-10/GE-10				4
5.	Dissertation on Major or Dissertation on Minor / Specialisation or Academic Project / Entrepreneurship					6
Total Credits						22

**Credits*
L (01 Credit) is equivalent to 01 contact hour per week
T (01 Credit) is equivalent to 01 contact hour per week
P (01 Credit) is equivalent to 02 contact hours per week

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Pool of DSEs offered by the Department

S. No.	Semester	DSE	Course Title
1.	VII	DSE – 5	Advanced DSP
2.			Digital ASIC Design: RTL to GDS - II
3.		DSE – 6	Analog Circuit Design: Modeling and Analysis
4.			Flexible Electronics and Wearable Technology
5.		DSE – 7	Introduction to Nonlinear Dynamics
6.			Verilog Ecosystem
7.	VIII	DSE – 8	Microwave Devices and Circuits
8.			Scientific Computing for Electronics
9.		DSE – 9	Optoelectronic Devices and Systems
10.			Introduction to Quantum Computing
11.		DSE – 10	AI for Wireless Communication
12.			Low Power VLSI Design

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Specialization and Minors offered by the Department

Semester	DSE/ GE	ECE Minor (Open only for CSE/ EE)	Specializations for ECE/ Minors for EE and CSE			
			Telecommunication Networks	VLSI Technology and System Design	IoT System Design	Computer Vision
VII	DSE-6/ GE-7	Applied MIMO and B5G Physical Layer Design	Photonic and Optical Communication Networks	Microwave Integrated Circuits	Edge IoT Prototyping with RTOS	Medical Image Processing
	DSE-7/ GE-8	Sensors and Actuators for Smart Systems	Optimization for Engineering	Analog VLSI Filter Design	Industry 4.0 and IIoT	Remote Sensing and Satellite Image Processing
VIII	DSE-9/ GE-9	Statistical Signal Processing	Wireless Systems Implementation	Introduction to Nonlinear Circuits	IoT Sensor and Data Integration	Forensic Image Processing
		Speech and Video Processing	Smart Antennas, Beamforming and OTA Testing for 5G/6G	RF Integrated Circuit Design	IoT Reliability Engineering	Computer Graphics
	DSE-10/ GE-10	Software Defined Radio and Waveform Engineering	Enabling Technologies for 6G Communication	Semiconductor Device Characterization	LPWAN IoT Networks	Computational Photography and Mobile Imaging
		Compressive Sensing and Sparse Representation	Estimation for Wireless Communication	Compact Modeling with Verilog-A	Edge Computing	Image Restoration and Inpainting

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Detailed Syllabus of Discipline Specific Core (DSC) Courses for B. Tech. (ECE) – Semester VII

Optical and Wireless Communication (DSC - 19)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Optical and Wireless Communication	4	3	0	1	Concepts of Digital Communication Systems

Course Objectives:

- Understand the principles of light propagation in optical fibers and signal degradation mechanisms.
- Design and analyze optical communication links considering power and bandwidth requirements.
- Characterize wireless channels and apply appropriate modulation and multiple access techniques.
- Evaluate performance of cellular and modern wireless communication systems.
- Apply knowledge of current and emerging optical and wireless technologies.

Course Outcomes:
After completing the course, the students should be able to:

1. Understand the fundamentals and architecture of optical and wireless communication systems.
2. Analyze optical fiber transmission, sources, detectors, and system impairments.
3. Explain wireless propagation mechanisms, fading, and noise effects.
4. Design and analyze basic optical and wireless communication links.
5. Evaluate the performance of modern communication systems used in real-world applications.

Unit – I **(11 hours)**
Introduction and Fundamentals of Optical Communication: Overview of communication systems and evolution of optical and wireless communications, Electromagnetic spectrum and applications, Principle of light propagation in optical fibers, Ray theory, modes of propagation, Step-index and graded-index fibers, Numerical aperture and acceptance angle, Types of optical fibers, Optical losses: absorption, scattering, bending losses, Dispersion: intermodal, material, and waveguide dispersion.

Unit – II **(12 hours)**
Optical Communication Components and Systems: Optical sources: LEDs and laser diodes, Characteristics and modulation techniques, Optical detectors: PIN and APD photodiodes, Receiver characteristics and noise sources, Optical amplifiers (EDFA, Raman amplifiers), Optical couplers, connectors, and splices, Optical transmitter and receiver design, Digital optical communication systems, Wavelength Division Multiplexing (WDM), Optical link power budget and rise-time budget, Free Space Optical (FSO) communication, Introduction to optical networks and passive optical networks (PON).

Unit – III **(11 hours)**
Fundamentals of Wireless Communication and Channel Modeling: Basics and architecture of wireless communication systems, Wireless channel characteristics, Propagation mechanisms: reflection, diffraction, scattering, Path loss models: free space, log-distance, Okumura-Hata, Noise and interference in wireless systems, Signal-to-noise ratio and channel capacity, Large-scale and small-scale fading, Statistical fading models: Rayleigh, Rician, Nakagami, Doppler effect and coherence time.

Unit – IV **(11 hours)**
Modern Wireless Systems and Emerging Technologies: Diversity techniques: time, frequency, and space diversity, Multiple-input multiple-output (MIMO) systems, Cellular communication concepts, Multiple access techniques: FDMA, TDMA, CDMA, OFDMA, Overview of 4G LTE and 5G systems, Optical wireless communication: VLC/LiFi, Hybrid optical–wireless systems, Millimeter-wave, terahertz communication, and 6G vision, Security challenges in optical and wireless communication.

Essential Readings
1. Wireless Communications by A. Goldsmith (Cambridge University Press)
2. Optical Fiber Communications by G. Keiser (McGraw-Hill)
3. Wireless Communications: Principles and Practice by T. S. Rappaport (Pearson)

Suggested Readings
1. Modern Control Systems by Richard C. Dorf and Robert H. Bishop (Pearson)
2. Optical Fiber Communications: Principles and Practice by J. M. Senior and M. Y. Jamro (Pearson)
3. Modern Wireless Communications by S. Haykin and M. Moher (Pearson)

List of Experiments (Hardware and Software using Matlab / Simulink – at least 5) **(30 hours)**

1. Simulation of numerical aperture and acceptance angle of step-index and graded-index optical fibers.
2. MATLAB-based analysis of attenuation and bending losses in optical fiber links.
3. Modeling and performance analysis of LED and Laser Diode characteristics for optical communication.
4. Simulation of optical receiver using PIN and APD photodiodes and noise analysis.
5. Optical link power budget and rise-time budget analysis using MATLAB.
6. Simulation and performance evaluation of WDM-based optical communication systems.
7. MATLAB simulation of wireless path loss models (Free-space, Log-distance, Okumura–Hata).
8. Simulation and analysis of wireless fading channels (Rayleigh, Rician, Nakagami).
9. BER and SNR performance analysis of digital modulation schemes (BPSK, QPSK) over wireless channels.
10. Performance evaluation of diversity and MIMO techniques in wireless communication using MATLAB.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

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Detailed Syllabus of Discipline Specific Elective (DSE) Courses for B. Tech. (ECE) – Semester VII

Advanced DSP (DSE - 5)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Advanced DSP	4	3	0	1	Concepts of Signals and Systems, Digital Signal Processing

Course Objectives:
- To study the fundamentals of multi-rate signal processing.
- To study the different linear prediction and optimum linear filters.
- To study different adaptive filters and Algorithms.
- To study the various nonparametric methods for power spectrum estimation.
- To study the various parametric methods for power spectrum estimation.

Course Outcomes:
After completing the course, the students should be able to:
1. Understand the fundamentals of sampling theory and multi-rate signal processing.
2. Understand the different linear predictions and optimum linear filters.
3. Understand the different adaptive filters.
4. Analyse the various nonparametric methods for power spectrum estimation.
5. Analyse the various parametric methods for power spectrum estimation.

Unit – I **(11 hours)**
Review of discrete-time signals and systems, DTFT and DFT; aliasing and band-limited signals. Sampling theory: bandpass sampling, reconstruction. Mult-irate systems: up-sampling and down-sampling, time-domain expressions, spectra of interpolated and decimated signals. Polyphase decomposition, efficient structures for decimators and interpolators, multistage decimation/interpolation, applications in sub-band coding and filter banks.

Unit – II **(12 hours)**
Linear Prediction and Optimum Linear Filters: Innovations Representation of a Stationary Random Process, Forward and Backward linear prediction, Solution of the Normal Equations, Properties of linear prediction-Error Filter, AR Lattice and ARMA Lattice-Ladder Filters.
Adaptive Filters: Adaptive direct-form FIR Filters- LMS Algorithms, Adaptive Direct-Form Filter- RLS Algorithms, Adaptive Lattice-Ladder Filters.

Unit – III **(11 hours)**

Power Spectral Estimation: Estimation of Spectra from Finite Duration Observations of a Signal, Periodogram, Nonparametric Methods for Power Spectral Estimation: Bartlett, Welch, Blackman and Tukey methods, Comparison of performance of Non-Parametric Power Spectrum Estimation Methods.

Unit – IV **(11 hours)**

Parametric Methods for Power spectrum estimation: Relationship between Auto-correlation and Model Parameters, Yule-Walker method for AR model parameters, Burg method for AR model parameter, Unconstrained Least Squares Methods for AR model parameter, Sequential Estimation methods for AR model parameter, Moving Average (MA) and ARMA Models Minimum Variance Method.

Essential Readings

1. Digital Signal Processing: Principles, Algorithms and Applications by J. G. Proakis and D. G. Manolakis (Pearson)
2. Statistical Digital Signal Processing and Modeling by Monson H. Hayes (Wiley)
3. Adaptive Filter Theory by Simon Haykin (Pearson)

Suggested Readings

1. Discrete-Time Signal Processing by A. V. Oppenheim and R. W. Schafer (Pearson)
2. Digital Signal Processing: A Computer-Based Approach by S. K. Mitra (McGraw Hill)
3. Multirate Systems and Filter Banks by P. P. Vaidyanathan (Prentice Hall)
4. Algorithm Collections for Digital Signal Processing Applications Using Matlab by E. S. Gopi (Springer)

List of Experiments (Hardware and Software using Matlab/Simulink) **(30 hours)**

1. Generation and visualization of basic discrete time signals; verification of sampling/aliasing using different sampling rates.
2. Implementation of up sampler, down sampler, and combined multistage rate converters; spectrum plots before/after rate change.
3. Design and implementation of FIR interpolation and decimation filters using window methods; verification of polyphase structure.
4. Estimation of PSD using periodogram, Bartlett, and Welch methods; comparison of resolution and variance.
5. AR model parameter estimation (Yule–Walker/Burg) and parametric PSD.
6. Design and simulation of an FIR Wiener filter for noise reduction in a noisy signal.
7. LMS adaptive filter for system identification or echo cancellation; study of step size effect on convergence.
8. RLS adaptive filter for channel equalization; comparison with LMS in terms of convergence speed.
9. Implementation of a chosen FIR/IIR or adaptive filter in real time on a DSP or embedded board

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Digital ASIC Design: RTL to GDS - II (DSE – 5)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Digital ASIC Design: RTL to GDS - II	4	2	0	2	Concepts of Digital Electronics / Digital System Design

Course Objectives:

- To develop practical RTL design skills using Verilog / VHDL for synthesizable digital hardware blocks.
- To introduce hands - on ASIC flow from RTL → netlist → floorplan → place → route → GDS-II using an EDA toolchain.
- To build ability to run and automate the flow using Tcl scripting (batch runs, parameter sweeps, reproducible builds).
- To develop practical verification skills using testbenches, and waveform debugging techniques.
- To expose students to FPGA prototyping as a hardware validation step.

Course Outcomes:

After completing the course, the students should be able to:

1. Write synthesizable Verilog / VHDL RTL for combinational / sequential systems, including FSMs and datapath / control modules.
2. Create self-checking testbenches, debug using waveforms, and validate corner cases with a structured verification workflow.
3. Run the RTL-to-GDS-II flow using industry-style steps (synthesis, floorplan, placement, CTS (overview), routing) and generate GDS-II outputs.
4. Interpret key reports: area, timing slack, power estimate, utilization, congestion and apply practical fixes (pipelining, constraints, floorplan tweaks).
5. Prototype RTL on FPGA and correlate hardware behavior with simulation results.

Unit – I **(15 hours)**

RTL Design Fundamentals: RTL constructs, combinational vs sequential. Adder, Counters. FSM, debouncing, and clock design.

Synthesis: RTL to gates / standard cells, optimization goals (timing / area). Constraints: clocks, input / output delays, false paths / multicycle. Timing essentials: critical path, setup / hold, slack. Gate-level simulation.

Unit – II **(15 hours)**

Physical Design Concepts: floorplanning, placement, clocking concept, routing, and generating final layout GDS-II. Congestion, wirelength trends, timing after placement / route, and area utilization.

Tcl scripting: running steps, setting variables. Parameter sweeps: clock period vs area / timing. STA / DRC / LVS checks. FPGA: Map RTL block to FPGA I/O (LED) for Hardware Validation.

Essential Readings
1. Digital Design and Computer Architecture by David Harris & Sarah Harris (Morgan Kaufmann)
2. FPGA Prototyping by Verilog Examples by Pong P. Chu (Wiley)
3. RTL Hardware Design Using VHDL by Pong P. Chu (Wiley)

Suggested Readings
1. Yosys Documentation (Official)
2. OpenROAD / OpenLane Documentation (Official)
3. KLayout / Magic Documentation (Official)

List of Experiments (Hardware based on FPGA boards / Software based on Open Source tools / Cadence)
(60 hours)

1. Write synthesizable RTL in Verilog/VHDL and verify reset/enable using simulation.
2. Design an FSM in Verilog / VHDL and validate state transitions with a testbench.
3. Implement a small datapath block and verify outputs using waveforms/pass-fail checks.
4. Run synthesis to generate a gate-level netlist and basic area/timing reports.
5. Improve timing by RTL optimization and compare before/after synthesis results.
6. Perform floorplanning by varying utilization/aspect ratio.
7. Run place-and-route to produce the final layout and GDS-II.
8. To use a TCL script for automating key steps.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Analog Circuit Design: Modeling and Analysis (DSE – 6)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Analog Circuit Design: Modeling and Analysis	4	3	0	1	Concepts of Electronic Devices and Circuits

Course Objectives:

- To understand the operation of four terminal MOS device and its use in multistage amplifier.
- To inculcate the ability to analyse frequency response and determine poles and zeros.
- To learn the essentials of current mirror and operational amplifier and their analysis
- To understand the various types of noise in amplifiers and their interference.

Course Outcomes:

After completing the course, the students should be able to:

1. Analyze MOS models and multistage amplifiers using Miller's theorem/Bode plots, while understanding the issues related to stability/noise.
2. Perform high/low-frequency analysis of MOS amplifiers using time-constant methods for bandwidth estimation.
3. Design CMOS op-amps and current mirrors with stability compensation.
4. Understand noise related issues, perform its modelling, compute S/N ratios, and evaluate harmonic distortion in amplifiers.

Unit – I **(12 hours)**

Basic MOS models – Low Frequency and High Frequency, Bulk Effect, Second order effects, short channel effects, multistage amplifiers and their small-signal analysis, cascade and cascode amplifier, folded cascode amplifier, Millers theorem, Bode plot, stability and noise issues in amplifiers.

Unit – II **(15 hours)**

High Frequency analysis of Single stage amplifiers (CS, CG, CD, CS amplifiers with source degeneration) with conventional and time constant methods. Dominant pole approach, Low frequency analysis of CS amplifier with time constant method. High frequency analysis of cascode amplifier. Step response of amplifier. Short circuit transconductance of common source amplifier, Input and output impedance of amplifier, bandwidth estimation.

Unit – III **(10 hours)**

Basic current mirrors, Wilson and Cascode current mirrors, CMOS Operational amplifiers: Single-Stage Op-Amps, Telescopic cascode Op-Amp, Folded-Cascode Op-Amps, Two-stage Op-Amps, Stability and Compensation.

Unit – IV **(08 hours)**

Signals, Information, Interference and noise, Statistical Characteristics of Noise, Types of Noise, S/N ratio, noise model for circuit analysis, input referred noise, noise analysis of amplifiers, total harmonic distortion.

Essential Readings

1. Analog MOS integrated circuits for signal processing by Gregorian, Roubik, and Gabor C. Temes (Wiley).
2. Microelectronic Circuits by Sedra, Adel S., and Kenneth C. Smith (Oxford University Press).
3. Design of Analog CMOS Integrated Circuits by Behzad Razavi (Tata McGraw-Hill)

Suggested Readings

1. CMOS Analog Circuit Design by Allen, Phillip E., and Douglas R. Holberg (Oxford University Press).
2. Microelectronics: Digital and Analog Circuits and Systems by Millman, Jacob, and Arvin Grabel (McGraw-Hill).
3. Analog integrated circuit design by Johns, David A., and Ken Martin (John Wiley & Sons).
4. Analysis and design of analog integrated circuits by Gray, Paul R., et al (Wiley).
5. CMOS Digital Integrated Circuits Analysis & Design by Sung-Mo Kang, Yusuf Leblebici, (McGraw-Hill)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Plot DC transfer curves for NMOS / PMOS (Id vs Vgs, Vds) showing cutoff, triode, saturation regions with short-channel effects (use 0.18μm models).
2. Compare voltage gain (Av), output impedance, and frequency response of basic NMOS gain stage vs cascode amplifier.
3. Simulate gain, phase margin, unity-gain bandwidth, and dominant pole location for Folded Cascode Amplifier.
4. Compare output impedance and compliance range of basic, Wilson, and cascode current mirrors.
5. Design and simulate open-loop gain, GBW, phase margin, and slew rate. Include stability analysis with unit-step response.
6. Implement Two-Stage Op-Amp with Miller compensation capacitor; plot phase margin improvement and settling time. Compare compensated vs uncompensated.
7. Calculate total RMS noise, input-referred noise voltage, and SNR for a cascode amplifier.
8. Simulate common-mode vs differential gain with active load. Plot CMRR vs frequency using dual-tone inputs.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Flexible Electronics and Wearable Technology (DSE – 6)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Flexible Electronics and Wearable Technology	4	3	0	1	Concepts of Electrical and Electronics Engineering / Electronic Devices and Circuits

Course Objectives:

- To introduce materials, device structures, and processes used in flexible and wearable electronics.
- To design basic flexible components (interconnects, sensors, TFT-style structures).
- To fabricate low cost flexible devices and characterize electrical performance using SMU / LCR / DMM setups.
- To model flexible structures and device behavior using EDA tools and correlate with measurements.

Course Outcomes:
After completing the course, the students should be able to:

1. Select suitable flexible substrates, conductors, and encapsulation for a wearable use case.
2. Fabricate basic flexible interconnects / sensors using low-cost methods and measure key electrical metrics and repeatability.
3. Perform bending / fatigue tests and quantify performance degradation.
4. Use EDA tools to simulate strain / electrical behavior and explain correlation gaps between model and measurements.

Unit – I **(10 hours)**
Basics of Flexible & Wearable Electronics: Applications and form factors (patch, band, textile), substrates (PET, PI/Kapton, TPU), conductors, encapsulation, wearable constraints and simple design rules.

Unit – II **(11 hours)**
Fabrication & Interconnect Design: Patterning methods (copper-tape, stencil/screen printing, vinyl-mask), curing, flexible interconnect (straight vs serpentine), connectors and contact resistance, packaging.

Unit – III **(12 hours)**
Wearable Sensors: Strain sensors (piezoresistive), pressure sensors (piezoresistive / capacitive), temperature sensing (RTD / NTC), basic bioelectrodes (ECG / EMG overview), signalling /calibration.

Unit – IV **(12 hours)**
Characterization: SMU / LCR / DMM (R–t, I–V, C–V), two-wire vs Kelvin sensing, bending / fatigue test protocols, failure modes, EDA based bending/strain hotspot simulation, EDA based device simulation.

Essential Readings

1. Flexible Electronics: Materials and Applications by William S. Wong & Alberto Salleo (Springer)
2. Wearable Sensors: Fundamentals, Implementation and Applications by Edward Sazonov & Michael R. Neuman (Academic Press)
3. Printed Electronics: Materials, Technologies and Applications by Zheng Cui (Wiley)

Suggested Readings

1. Stretchable Electronics by Takao Someya (Wiley)
2. Bioelectronics: From Theory to Applications edited by Itamar Willner and Eugenii Katz (Wiley, 2005)
3. Flexible Electronics: From Materials to Devices by Guozhen Shen and Zhiyong Fan (World Scientific)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Build and test flexible interconnects and measure basic electrical resistance and contacts.
2. Compare different trace geometries under bending and repeated flexing.
3. Develop a basic strain sensor and evaluate sensitivity and repeatability.
4. Model and optimize strain sensing structures using simulation / EDA tools.
5. Model and optimize pressure-sensing structures using simulation / EDA tools.
6. Prototype a pressure sensor and characterize key performance metrics.
7. Prototype a temperature sensor and perform calibration and stability checks.
8. Develop wearable electrode structures and evaluate electrical interface quality.
9. Simulate multilayer flexible stacks to identify high-stress regions and failure risks.
10. Perform simple reliability testing and track performance degradation trends.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Introduction to Nonlinear Dynamics (DSE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Introduction to Nonlinear Dynamics	4	3	0	1	NIL

Course Objectives:

- Introduce the fundamental concepts of nonlinear dynamical systems and state-space analysis.
- Develop qualitative and quantitative understanding of one- and two-dimensional nonlinear systems.
- To train students in phase-line and phase-plane methods for analysing system behaviour.
- Provide a rigorous foundation in linearization and local stability theory.
- Explain how bifurcations arise in parameter-dependent systems.
- Introduce the mathematical mechanisms leading to chaos.
- Familiarize students with nonlinear oscillators and driven systems.
- To build analytical and computational skills for studying real physical and engineering systems.

Course Outcomes:
After completing the course, the students should be able to:

1. Formulate dynamical systems and analyze one-dimensional nonlinear flows.
2. Apply linearization methods to determine local stability of equilibria.
3. Construct and interpret phase-plane portraits of two-dimensional systems.
4. Classify bifurcations and identify routes to chaos in nonlinear systems.
5. Analyze nonlinear oscillators and chaotic systems using analytical and numerical tools.

Unit – I **(10 hours)**
Dynamical systems and state space; autonomous first-order differential equations; fixed points and phase-line analysis; stability of equilibria; nonlinear flows; physical interpretation and potential analogy; global versus local behavior; examples from population dynamics, reaction kinetics, and particle motion.

Unit – II **(10 hours)**
Linear systems in one dimension; exponential growth and decay; relaxation time scales; linearization of nonlinear systems; Jacobian in one dimension; local stability criteria; marginal stability and breakdown of linear models; influence of nonlinear terms; critical slowing down.

Unit – III **(10 hours)**
Planar dynamical systems; phase space and trajectories; linear systems in two dimensions; classification of fixed points (nodes, saddles, spirals, centers); eigenvalues and eigenvectors; nullclines and graphical methods; conservative and dissipative systems; limit cycles; Poincaré–Bendixson theorem; nonlinear oscillators (Van der Pol, Duffing type systems).

Unit – IV **(15 hours)**
Parameter-dependent systems; local bifurcations: saddle-node, transcritical, pitchfork and Hopf bifurcations; normal forms and universality; routes to chaos; logistic map and iterated maps; period-doubling cascade; bifurcation diagrams; sensitive dependence on initial conditions; strange attractors; Poincaré sections; chaos in driven nonlinear oscillators.

Suggested Readings

1. Nonlinear Dynamics and Chaos by Steven H. Strogatz (CRC Press)
2. Deterministic Chaos by H. G. Schuster and W. Just (Wiley-VCH)
3. Chaos in Dynamical Systems by Edward Ott (Cambridge University Press)

Essential Readings

1. Chaos: An Introduction to Dynamical Systems by Kathleen Alligood, Tim Sauer, and James Yorke (Springer)
2. Nonlinear Dynamics and Chaos by J. M. T. Thompson and H. B. Stewart (Wiley)

List of Experiments (Software using Matlab) **(30 hours)**

1. Phase-line simulations.
2. Numerical integration of nonlinear ODEs.
3. Phase-plane plotting; limit-cycle detection.
4. Construction of bifurcation diagrams.
5. Poincaré maps; Lyapunov exponent estimation.
6. Chaos in Duffing and driven oscillator models.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Verilog Ecosystem (DSE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Verilog Ecosystem	4	2	0	2	Basic Programming Skills and Fundamentals of Digital Electronics / Digital System Design

Course Objectives:

- To develop practical coding skills in Verilog HDL including synthesizable RTL and simulation-only constructs.
- To introduce SystemVerilog for modern RTL, interfaces, packages, and verification features.
- To expose students to SystemVerilog Assertions (SVA) and basic coverage for bug-catching.
- To provide working exposure to Verilog-A / Verilog-AMS for behavioral modeling of analog / mixed-signal blocks.

Course Outcomes:

After completing the course, the students should be able to:

1. Write clean synthesizable RTL using Verilog HDL and distinguish synthesizable vs testbench-only constructs.
2. Use SystemVerilog features (always_ff/always_comb, enum, struct, interface, package) to write safer, scalable RTL.
3. Develop verification testbenches using SystemVerilog (classes-light, constrained random basics, functional coverage basics) and debug using waveforms/logs.
4. Write simple SystemVerilog Assertions (SVA) to check protocols/invariants and improve debug productivity.
5. Create basic Verilog-A/AMS behavioral models (e.g., diode/opamp/RC/sensor) and run mixed-signal style simulations at a conceptual level.

Unit – I **(15 hours)**

Verilog RTL: modules/ports/parameters, nets vs reg/logic, timescale; synthesizable combinational vs sequential coding, basic datapath blocks, and simulation basics ($display/$monitor, waveform dump).

Modern Verilog: generate blocks, parameters/localparams, functions/tasks; synthesizable coding, basic clock/reset strategy, and gate-level netlist concept.

Unit – II **(15 hours)**

SystemVerilog: always_comb/ff, typedef/enum/struct, packed arrays, interfaces/packages; basic verification and assertions (simple).

Verilog-A fundamentals: analog behavioral modeling approach, simple continuous-time models (RC / diode / opamp), and a high-level view of mixed-signal blocks (ADC/DAC).

Essential Readings

1. SystemVerilog for Design: A Guide to Using SystemVerilog for Hardware Design and Modeling by Stuart Sutherland, Simon Davidmann, and Peter Flake (Springer)
2. The Verilog® Hardware Description Language by Donald E. Thomas and Philip R. Moorby (Springer)
3. Verilog-A: Analog Behavioral Modeling by Ken Kundert and Olaf Zinke (Springer).

Suggested Readings

1. IEEE 1364 Verilog HDL Standard and IEEE 1800 SystemVerilog Standard.
2. FPGA Prototyping by SystemVerilog Examples: Xilinx MicroBlaze MCS SoC Edition by Pong P. Chu (Wiley)
3. SystemVerilog for Verification: A Guide to Learning the Testbench Language Features by Chris Spear and Greg Tumbush (Springer)

List of Experiments (Hardware / Software) **(60 hours)**

1. Write an RTL module and verify using simulation and waveforms.
2. Implement sequential RTL and validate timing behavior in simulation.
3. Design an FSM and verify state transitions using a testbench.
4. Use parameterization/generate constructs to build scalable N-bit logic.
5. Write RTL using SystemVerilog constructs.
6. Create and use a simple interface to connect DUT and testbench.
7. Develop a SystemVerilog testbench and run directed tests for a small DUT.
8. Build a reusable verification setup (non-UVM) and adapt it across multiple DUTs.
9. Create simple Verilog-A behavioral models and validate expected responses.
10. Set up a basic mixed-signal simulation with digital stimulus interacting with an analog model.

(Note: Course instructor may add/ delete / update new experiments in addition to the above suggested practical exercises.)

Department of Electronics and Communication Engineering
Faculty of Technology
University of Delhi

Detailed Syllabus of Discipline Specific Core (DSC) Courses for B. Tech. (ECE) – Semester VIII

RF and Microwave Engineering (DSC - 20)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
RF and Microwave Engineering	4	3	0	1	Concepts of Electromagnetic Theory

Course Objectives:
- To make students comfortable with RF by focusing on measurement and tuning.
- To teach core industry skills: S-parameters, VNA use, matching networks, RF prototyping.
- To design, fabricate, and test real antennas and RF blocks relevant to IoT/Wi-Fi/ISM bands.
- To introduce practical EMI/EMC debugging and RF system thinking with link budgets and RSSI validation.

Course Outcomes:
After completing the course, the students should be able to:
1. Measure and interpret S11/S21, VSWR, return loss, and apply them to improve RF designs.
2. Design and validate matching networks and simple RF filters using simulation + VNA measurement.
3. Design, prototype, and tune a 2.4 GHz antenna and evaluate performance changes due to enclosure / hand effects.
4. Perform an RF link budget and verify predictions using RSSI/measurement logs.

Unit – I **(11 hours)**
RF Measurements: RF frequency view (phasors, complex impedance/admittance, dB/dBm, noise floor intuition), two-port network for RF circuits, S – parameters, return loss / VSWR / bandwidth, VNA measurement, error sources, repeatability, time-domain view using VNA.

Unit – II **(12 hours)**
Transmission Lines & Matching: Distributed vs lumped behavior, transmission line parameters, impedance transformation, Smith chart basics, networks: L-network / π/T / stub matching / quarter-wave transformer, matching for antennas vs matching for amplifiers, stability / oscillation, and RF layout matching.

Unit – III **(12 hours)**
Planar RF Blocks: Planar transmission, microstrip design for 50Ω, discontinuities (bends / steps / tees), resonators (λ/4, λ/2), filter design (fc, BW, ripple, IL), couplers and power dividers (Wilkinson), RF switches / attenuators, mixers and frequency, oscillators / PLLs and phase noise.

Unit – IV **(10 hours)**
Antennas, System Integration and EMI/EMC: Monopole / dipole / patch tuning by S11, antenna efficiency, Friis, RSSI, EMI / EMC coupling paths, shielding / grounding.

Essential Readings

1. RF Circuit Design: Theory and Applications by Reinhold Ludwig and Gene Bogdanov (Pearson)
2. Microwave Transistor Amplifiers: Analysis and Design by Guillermo Gonzalez (Pearson)
3. Microwave Engineering by David M. Pozar (Wiley)

Suggested Readings

1. Antenna Theory: Analysis and Design by Constantine A. Balanis (Wiley)
2. Foundations for Microwave Engineering by Robert E. Collin (McGraw-Hill)
3. ARRL Handbook (selected practical RF measurement sections)

List of Experiments (Hardware / Software using Matlab/Simulink – at least 5) **(30 hours)**

1. Use a VNA to measure basic RF components (loads/cables/antennas) and perform calibration.
2. Interpret S-parameters (return loss/VSWR) for impedance matching quality.
3. Design and validate a simple matching network to improve S11.
4. Implement stub-based matching and verify tuning impact through measurement.
5. Design and test a controlled-impedance transmission line and measure insertion loss (S21).
6. Build and characterize a basic RF filter and measure bandwidth/attenuation.
7. Design, tune, and evaluate a 2.4 GHz antenna to meet a target match level.
8. Perform basic RF system checks using range tests, link budget comparison, and spectrum/EMI measurements.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Department of Electronics and Communication Engineering
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Detailed Syllabus of Discipline Specific Elective (DSE) Courses for B. Tech. (ECE) – Semester VIII

Microwave Devices and Circuits (DSE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Microwave Devices and Circuits	4	3	0	1	Concepts of Electromagnetic Theory and Communication Systems

Course Objectives:
- Introduce fundamental concepts of microwave passive and active devices.
- Understand the operation of microwave semiconductor devices and tubes.
- Develop knowledge of microwave circuit design (matching, filters, amplifiers).
- Familiarize students with microwave measurement techniques and instruments.
- Expose students to microwave systems and modern applications.

Course Outcomes:
After completing the course, the students should be able to:
1. Explain the principles and characteristics of microwave passive and active components.
2. Analyze microwave semiconductor devices and vacuum tubes.
3. Apply microwave design techniques for matching, filters, amplifiers, oscillators, and antennas.
4. Perform and interpret microwave measurements using standard instruments.
5. Describe microwave systems such as radar, satellite communication, navigation, and RFID.
6. Understand modern microwave technologies including MMICs, RF MEMS, imaging, and EMI/EMC.

Unit – I **(11 hours)**
Passive and Active Microwave Devices: Microwave passive components: Directional Coupler, Power Divider, Magic Tee, Attenuator, Resonator. Microwave active components: Diodes, Transistors, Oscillators, Mixers. Microwave Semiconductor Devices: Gunn Diodes, IMPATT diodes, Schottky Barrier diodes, PIN diodes. Microwave Tubes: Klystron, TWT, Magnetron.

Unit – II **(12 hours)**
Microwave Design Principles: Impedance transformation, Impedance Matching, Microwave Filter Design, RF and Microwave Amplifier Design, Microwave Power Amplifier Design, Low Noise Amplifier Design, Microwave Mixer Design, Microwave Oscillator Design. Microwave Antennas- Antenna parameters, Antenna for ground-based systems, Antennas for airborne and satellite borne systems, Planar Antennas.

Unit – III **(11 hours)**

Microwave Measurements: Power, Frequency and impedance measurement at microwave frequency, Network Analyzer and measurement of scattering parameters, Spectrum Analyzer and measurement of spectrum of a microwave signal, Noise at microwave frequency and measurement of noise figure. Measurement of Microwave antenna parameters.

Unit – IV **(11 hours)**

Microwave Systems: Radar, Terrestrial and Satellite Communication, Radio Aidsto Navigation, RFID, GPS. Modern Trends in Microwaves Engineering- Effect of Microwaves on human body, Medical and Civil applications of microwaves, Electromagnetic interference and Electromagnetic Compatibility (EMI & EMC), Monolithic Microwave ICs, RFMEMS for microwave components, Microwave Imaging.

Essential Readings

1. Microwave Engineering by David M. Pozar (John Wiley & Sons, 4th Edition)
2. Microwave Devices and Circuits by Samuel Y. Liao (Pearson / PHI, 3rd Edition)
3. RF Circuit Design: Theory and Applications by Christopher Bowick (Elsevier)

Suggested Readings

1. Foundations for Microwave Engineering by Robert E. Collin, (Wiley India, 2nd Edition)
2. Microwave Engineering by Annapurna Das and Sisir K. Das (Tata McGraw-Hill)
3. Microwave Circuits and Passive Devices by M. L. Sisodia and G. S. Raghuvanshi (New Age International)
4. Microwave and Radar Engineering by M. Kulkarni (Umesh Publications)

<u>**List of Experiments**</u> (Hardware / Software – at least 5) **(30 hours)**

1. Study of various microwave components and instruments.
2. Measurement of guide wavelength and frequency using a X-band slotted line setup. Measurement of low and high VSWR using a X-band slotted line setup.
3. Draw the V-I characteristics of a Gunn diode and determine the output power and frequency as a function of voltage.
4. Study the square wave modulation of microwave signal using PIN diode.
5. Study and measure the power division and isolation characteristics of a microstrip 3dB power divider.
6. Study of rat race hybrid ring (equivalent of waveguide Magic-Tee) in micro-strip.
7. To study the characteristics of micro-strip 3dB branch line coupler, strip line backward wave coupler as a function of frequency and compare their bandwidth.
8. Measure the microwave input, direct, coupled, and isolated powers of a backward wave strip line coupler at the centre frequency using a power meter. From the measurements calculate the coupling, isolation, and directivity of the coupler.
9. Study of field pattern of various modes inside a rectangular and circular waveguide.
10. Find the change in characteristics impedance and reflection coefficients of the transmission line by changing the dielectric properties of materials embedded between two conductors.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Scientific Computing for Electronics (DSE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Scientific Computing for Electronics	4	3	0	1	NIL

Course Objectives:

- To introduce students to Linear Programming techniques for optimal allocation of resources.
- To develop understanding of transportation and network models used in operations research.
- To apply project management techniques such as CPM and PERT for planning and scheduling.
- To familiarize students with decision-making methods under uncertainty, risk, and conflict.
- To build analytical skills for solving real-life managerial and optimization problems.

Course Outcomes:

After completing the course, the students should be able to:

1. Formulate and solve Linear Programming Problems using graphical and simplex methods.
2. Solve transportation and network optimization problems using standard techniques.
3. Analyze project scheduling using CPM and PERT, including floats and time-cost trade-off.
4. Apply decision theory models to make decisions under uncertainty and risk.
5. Solve game theory problems using maximin, minimax, dominance rule, and graphical methods.

Unit – I **(11 hours)**

Linear Programming: Formulation of L.P. Problems, Graphical Solutions (Special cases: Multiple optimal solution, infeasibility, unbounded solution); Simplex Method, Special cases, Big-M method and Two-phase method; Duality (emphasis on formulation & economic interpretation);

Unit – II **(11 hours)**

Transportation: Formulation of Transportation Problems, Solution by N.W. Corner Rule, Least Cost method, Vogel's Approximation Method (VAM), Modified Distribution Method; Special cases: Multiple Solutions, Maximization case, unbalanced case, prohibited routes.

Unit – III **(10 hours)**

Network Analysis: Basic Concept, Construction of the Network diagram, Critical Path Analysis, float and slack analysis (Total float, free float, independent float), probability consideration in PERT, Time-Cost optimization in Project. (Interface with Project Management software)

Unit – IV **(13 hours)**

Decision Theory: Decision making environment, Construction of Pay off Table, Opportunity Loss Table, Decision under uncertainty, Decision under Risk: EMV, EOL, EVPI.
Decision under Conflict: Game Theory, Two person Zero-Sum games, Maximin Minimax Principle, Games without Saddle point- Mixed strategy, Dominance Rule; Reduction of m x n game and solution of 2×2, 2 x s, and r x 2 cases by Graphical Method.

Essential Readings

1. Operations Research: An Introduction by Hamdy A. Taha (Pearson)
2. Introduction to Operations Research by Hillier & Lieberman (McGraw Hill)
3. Linear Programming and Network Flows by M. S. Bazaraa and J.J. Jarvis (John Wiley & Sons)

Suggested Readings

1. Quantitative Techniques in Management by N. D. Vohra (McGraw)
2. Operations Research: Theory and Applications by J.K. Sharma (Macmillan India Limited)
3. Operations Research by Kanti Swarup, P.K. Gupta, Man Mohan (S Chand & Sons)

List of Experiments (Software using MATLAB / Python – at least 5) **(30 hours)**

1. Formulate real-life problem (production, diet, blending) into LP models and solve using Simplex method.
2. To implement two phase method for a given problem.
3. To implement Big M method for a diet problem.
4. To implement a given problem using Dual formulation and verify primal-dual relationships.
5. To analyze and implement Vogel's Approximation Method for a given transportation problem.
6. To implement optimization technique for Transportation using MODI method.
7. To construct and analyze project networks.
8. To perform scheduling analysis of project activities.
9. To analyze project completion time and uncertainty in project networks.
10. To study decision-making models and game theory concepts.
11. To design a mini project based on the latest trends in industry.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Optoelectronic Devices and Systems (DSE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Optoelectronic Devices and Systems	4	3	0	1	Introduction to Electrical and Electronics Engineering / Basics of Semiconductor Devices

Course Objectives:

- To introduce the fundamental principles of light–semiconductor interaction relevant to optoelectronic devices.
- To develop an understanding of the structure, operation, and characteristics of semiconductor optical sources, including LEDs and laser diodes.
- To explain the working principles and performance parameters of semiconductor photodetectors.
- To emphasize device physics and operating mechanisms governing optoelectronic components.
- To provide an overview of current research trends and industrial developments in optoelectronics and nanophotonics.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain optical absorption, emission, and amplification mechanisms in semiconductors.
2. Describe the structure and operation of semiconductor light sources and optical amplifiers.
3. Analyze photodetector performance and noise.
4. Understand how optoelectronic devices are integrated with electronic circuits in modern VLSI and CMOS platforms.
5. Understand emerging research directions in nanophotonics and integrated optoelectronics, and their relevance to future electronic systems.

Unit – I **(11 hours)**

Interaction of light with semiconductors. Optical absorption and emission processes. Recombination Mechanisms. Emission and absorption rates. Population inversion and optical gain in semiconductors. Principles of optical signal amplification. Material parameters affecting absorption, emission, and gain.

Unit – II **(12 hours)**

Semiconductor Light Sources: Light Emitting Diodes (LEDs): basic structure, theory of operation, spectral characteristics, efficiency, and modulation bandwidth. Semiconductor lasers: operating principle, threshold condition, resonant cavities, and device characteristics. Types of semiconductor lasers: homojunction and heterojunction lasers, quantum well lasers, DFB and DBR lasers, and VCSELs. Modulation of semiconductor lasers: direct and external modulation (conceptual). Semiconductor Optical Amplifiers (SOAs): structure, gain characteristics, and applications.

Unit – III **(11 hours)**

Semiconductor Photodetectors: Principles. Photon absorption and carrier generation. Photodetectors: PN, PIN, and avalanche photodiodes (APDs). Device structure, theory of operation, and characteristics. Responsivity, quantum efficiency, response time, and bandwidth limitations. Loss and noise mechanisms: shot noise and thermal noise (qualitative). Solar cells: principle and characteristics. Charge Coupled Devices (CCDs): structure and operation. Introduction to integrated optoelectronic detector circuits.

Unit – IV **(11 hours)**

Emerging Optoelectronic Technologies and Integration: Introduction to nanophotonic devices: quantum dots, nanowires, and photonic crystals (conceptual). Role of nanoscale confinement in enhancing emission and detection. Integrated optoelectronic circuits and CMOS-compatible photonic devices. Overview of silicon photonics, challenges in integration, scaling, power dissipation, and packaging. Future directions in optoelectronic and electronic co-integration.

Essential Readings

1. Semiconductor Optoelectronic Devices by Pallab Bhattacharya (Pearson)
2. Fundamentals of Photonics by B. E. A. Saleh and M. C. Teich (Wiley)
3. Physics of Semiconductor Devices by S. M. Sze and K. K. Ng (Wiley)

Suggested Readings

1. COMSOL Multiphysics Documentation: Wave Optics & Semiconductor Modules (COMSOL)
2. Optoelectronics and Photonics: Principles and Practices by S. O. Kasap (Pearson)
3. Silicon Photonics: An Introduction by Graham T. Reed and Andrew P. Knights (Wiley)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Measurement and analysis of the current–voltage (I–V) characteristics of a light-emitting diode (LED).
2. Experimental investigation of the relationship between applied voltage and optical output intensity of a semiconductor laser diode.
3. Characterization of diffraction grating parameters using a semiconductor laser source.
4. Experimental verification of Malus' law for plane-polarized light.
5. Experimental study and characterization of the performance characteristics of a photodetector.
6. Characterization of solar cell performance through I–V analysis and determination of fill factor and conversion efficiency.
7. Experimental study of the electro-optic effect using a semiconductor laser diode.
8. Determination of the numerical aperture of an optical fiber using a semiconductor laser source.
9. Modelling and analysis of silicon optical waveguides for evaluation of guided mode profiles and effective refractive index.
10. Simulation of nanophotonic structures such as photonic crystals or optical resonators to study enhanced light confinement.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Introduction to Quantum Computing (DSE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Introduction to Quantum Computing	4	3	0	1	NIL

Course Objectives:

- Introduce the fundamental principles of quantum computing and the differences with classical computing
- Develop understanding of qubits, quantum states, superposition and entanglement
- Provide hands-on experience in designing, simulating, and executing quantum circuits
- Explain foundational quantum algorithms and their implementation
- Expose students to modern quantum computing frameworks and real quantum hardware

Course Outcomes:
After completing the course, the students should be able to:

1. Articulate the basic concepts of quantum mechanics relevant to quantum computing.
2. Represent and manipulate quantum states using Dirac notation and matrices.
3. Construct quantum circuits using standard quantum gates.
4. Implement and simulate quantum programs in Python using Qiskit.
5. Explain and demonstrate key quantum algorithms such as Deutsch, Grover, and Shor.
6. Compare quantum and classical computation through examples and real hardware execution.

Unit – I **(10 hours)**
What is quantum computing; classical vs quantum computing principles, Qubit, quantum state, binary vs quantum information, Complex vector spaces, state amplitudes and normalization, Superposition and interference, Entanglement and multi-qubit systems, Measurement and probability interpretation

Unit – II **(10 hours)**
Single-qubit gates: X, Y, Z, H (Hadamard), phase gates, multi-qubit gates: CNOT, Toffoli, SWAP, Quantum circuit notation and design, Universality of gate sets, Quantum teleportation and superdense coding, Simulation tools and circuit visualization

Unit – III **(10 hours)**
Simple algorithm examples: Deutsch and Bernstein–Vazirani, Grover's Search Algorithm (amplitude amplification), Quantum Fourier Transform (QFT) and Phase Estimation, Shor's factoring algorithm (conceptual overview and circuits), Algorithm performance and comparisons with classical counterparts

Unit – IV **(15 hours)**
Introduction to Python for quantum computing, IBM Qiskit framework: installation, basics, and workflow, Writing and simulating quantum programs, Running quantum circuits on real hardware (cloud-based IBMQ), Practical use cases and future trends in quantum computing, Optimization and error considerations in quantum circuits

Essential Readings

1. Qiskit Textbook by the Qiskit Community (Online, Open-Access)
2. Programming Quantum Computers by Eric R. Johnston, Nic Harrigan, and Mercedes Gimeno-Segovia (O'Reilly Media)
3. Learn Quantum Computing with Python and Qiskit by Various Authors (Various Online Resources)

Suggested Readings

1. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang (Cambridge University Press)
2. Introduction to Quantum Mechanics by David J. Griffiths (Pearson)
3. Quantum Computing: A Gentle Introduction by Eleanor Rieffel and Wolfgang Polak (MIT Press)

List of Experiments (Hardware / Software) **(30 hours)**

1. Quantum circuits simulation using Qiskit
2. Bloch sphere visualization exercises
3. Implementation of standard quantum gates and entanglement generation
4. Grover's and Deutsch algorithms on simulators
5. Execution of simple circuits on real IBM quantum hardware
6. Projects on quantum algorithms or application case studies

(Note: Course instructor may add / delete/ update new experiments in addition to the above suggested practical exercises.)

AI for Wireless Communication (DSE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
AI for Wireless Communication	4	3	0	1	Optical and Wireless Communication, Signals and Systems

Course Objectives:

- To introduce Python programming and machine learning techniques for wireless communication applications.
- To develop an understanding of modern wireless communication systems such as OFDM, MIMO, and OTFS through simulation.
- To apply machine learning and deep learning models for signal processing, estimation, and detection in wireless systems.
- To familiarize students with AI-enabled physical layer techniques aligned with 3GPP standards.
- To enable students to design and analyze intelligent wireless communication systems using data-driven approaches.

Course Outcomes:

After completing the course, the students should be able to:

1. Implement Python-based simulations for basic and advanced wireless communication systems.
2. Apply machine learning and deep learning techniques for classification, estimation, and detection of wireless signals.
3. Analyze the performance of OFDM, MIMO, and OTFS systems under realistic channel conditions.
4. Design AI/ML-based solutions for channel estimation, modulation classification, spectrum sensing, and NOMA detection.
5. Develop intelligent wireless communication models aligned with 3GPP standards such as CSI feedback, beamforming, and autoencoder-based PHY design.

Unit – I **(11 hours)**

Introduction to Python and Machine Learning Fundamentals: Basics of Python programming: data types, control structures, functions, libraries, Python scientific stack: NumPy, SciPy, Matplotlib, Introduction to Python for signal processing and wireless simulations, Introduction to Machine Learning, Learning paradigms: supervised, semi-supervised, and unsupervised learning, Regression models and classification overview, Support Vector Machines (SVM), K-Nearest Neighbors (KNN), Introduction to neural networks and learning concepts

Unit – II **(12 hours)**

Deep Learning Techniques for Wireless Applications: Artificial Neural Networks (ANN), Deep Neural Networks (DNN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM), Generative Adversarial Networks (GANs), Transfer learning concepts and applications, Reinforcement Learning (RL) fundamentals, Use of deep learning frameworks (TensorFlow / PyTorch – conceptual overview)

Unit – III **(11 hours)**

Wireless Communication Systems and Python-Based Modeling: Introduction to wireless communication systems, Single-carrier transmission systems, Orthogonal Frequency Division Multiplexing (OFDM), Multiple-Input Multiple-Output (MIMO) systems, Orthogonal Time Frequency Space (OTFS) modulation, Python-based simulation of single-carrier, OFDM, MIMO, and OTFS systems, Channel models and noise modeling.

Unit – IV **(11 hours)**

AI/ML-Enabled Wireless Signal Processing and Detection: Source coding and channel coding techniques, Modulation and wireless signal classification, Channel estimation techniques, Autoencoder-based wireless signal classification (3GPP-aligned concepts), CSI compression and feedback using autoencoders (3GPP standards), Beamforming and beam management using AI (3GPP perspective), Autoencoder–decoder architectures for PAPR reduction, Spectrum sensing using ML techniques, Successive interference cancellation for NOMA systems, AI/ML-based signal estimation and detection:
Parameter estimation and IF estimation, MIMO/OFDM/OTFS detectors, Denoising of wireless signals

Essential Readings

1. Wireless Communications by A. Goldsmith (Cambridge University Press)
2. Neural Networks and Learning Machines by S. Haykin (Pearson)
3. Deep Learning by Goodfellow *et al.* (MIT Press)

Suggested Readings

1. Wireless Communications and Applications Above 100 GHz: Opportunities and Challenges for 6G and Beyond by T. S. Rappaport *et al.* (IEEE Access)
2. An Introduction to Deep Learning for the Physical Layer by O'Shea and Hoydis (IEEE Transactions on Cognitive Communications)
3. Python documentation and open-source wireless ML frameworks.

List of Experiments (Software based – at least 5) **(30 hours)**

1. Python-based signal generation, noise modeling, and spectral analysis for wireless communication.
2. Simulation of a single-carrier wireless communication system and BER analysis over AWGN and fading channels.
3. Design and performance evaluation of an OFDM system using Python.
4. Simulation and analysis of MIMO wireless systems with linear detection techniques.
5. Modeling and performance comparison of OTFS and OFDM systems in high-mobility channels.
6. Machine learning–based modulation classification using KNN/SVM/CNN.
7. Deep learning–based channel estimation for OFDM/MIMO wireless systems.
8. Autoencoder-based end-to-end wireless communication, CSI compression, and PAPR reduction.
9. ML-based spectrum sensing and successive interference cancellation for NOMA systems.
10. AI/ML-based signal estimation, detection, and denoising including STO, CFO, and symbol rate estimation.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Low Power VLSI Design (DSE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Low Power VLSI Design	4	3	0	1	Concepts of Signals and Systems, Digital Electronics – I

Course Objectives:

- To introduce power/energy fundamentals and the need for low-power CMOS VLSI design.
- To understand sources of power dissipation and key design parameters affecting power.
- To learn a practical low-power design flow and basic power estimation methods from circuit to architecture level.
- To study essential low-power techniques at circuit, logic, and architecture/system levels.
- To expose students to challenges in low power analog circuits and related tecniques.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain dynamic and static power dissipation mechanisms in CMOS and the parameters that influence them.
2. Perform basic power estimation using simulation/activity and interpret power reports at different abstraction levels.
3. Apply circuit- and logic-level low-power techniques such as multi-VDD, sizing, multi-Vt, gating, and encoding.
4. Relate architecture choices to switching activity and overall energy efficiency.
5. Describe standby and runtime power management techniques such as clock/power gating and DVFS.
6. Understand the issues and possible solutions for power management in analog circuits.

Unit – I **(12 hours)**

Introduction to IC design: Basics of analog and digital circuits, design challenges in nano scale CMOS technology. Need for low power VLSI chips; Power vs energy and energy-delay; Power dissipation; Charging and Discharging Capacitance, Short-circuit Current in CMOS Circuit, CMOS Leakage Current, Static Power & Dynamic Power, Parameters for low power design (VDD, capacitance, frequency, VTH, temperature); Design approaches (device / circuit / logic / architecture); Device and technology impact on low power.

Unit – II **(13 hours)**

Low Power architecture: Supply voltage scaling, Device Feature Size Scaling, Architectural-Level Approaches, Voltage Scaling Using High-Level Transformations, Multilevel Voltage Scaling, Dynamic Voltage and Frequency Scaling, Adaptive Voltage Scaling, Subthreshold Logic Circuits, clock gating and clock management, Pipelining and parallelization to reduce supply voltage, Transistor and Gate Sizing, Logical Effort Theory.

Unit – III **(10 hours)**
Low Power Techniques: power consumption in circuits; Dynamic power optimization (multi-V_{DD} concept) and transistor sizing; Static power optimization (multi-V_T concept); Low-power sequential elements (flip-flop / latch power behavior); Logic-level techniques: gate reorganization to reduce glitches.

Unit – IV **(10 hours)**
Low power Analog integrated circuits: challenges in low voltage analog circuit design, Issues about low power supply voltage, roadmap, design of analog circuits using low voltage/low power implementation techniques such as Body bias, Bulk driven, self cascode structure, flipped voltage follower, FG, QFGMOS, DTMOS etc. Weak inversion operation

Suggested Readings

1. Low-Power VLSI Circuits and Systems by Ajit Pal (Springer)
2. Low Power Design Methodologies by J. M. Rabaey and M. Pedram (Springer)
3. Practical Low Power Digital VLSI Design by Gary K. Yeap (Springer)

Suggested Readings

1. Digital Integrated Circuits: A Design Perspective by J. M. Rabaey, A. P. Chandrakasan and B. Nikolic (PH/Pearson)
2. Low-Power CMOS VLSI Circuit Design by K. Roy and S. C. Prasad (Wiley)
3. Low-Power CMOS Design by P. Chandrakasan and R. W. Brodersen (IEEE Press)
4. Leakage in Nanometer CMOS Technologies by Siva Narendra and Anantha Chandrakasan (Springer)
5. CMOS VLSI Design: A Circuits and Systems Perspective by Neil H. E. Weste and David Harris (Pearson)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Estimate dynamic and leakage power of basic CMOS logic across voltage and temperature conditions.
2. Analyze power in small combinational blocks and identify dominant switching and capacitive nodes.
3. Evaluate clock gating techniques and quantify power savings on sequential logic.
4. Explore multi-voltage domain concepts and assess impact on power and design complexity.
5. Compare threshold-voltage options to study leakage vs performance trade-offs.
6. Apply techniques to reduce glitch / switching power through logic-level optimization.
7. Compare FSM implementation choices and observe switching activity and power differences.
8. Study clock distribution power trends using simple clock-tree modeling approaches.
9. Design and compare the power consumption in a bulk-driven amplifier.
10. Study of power consumption in FGMOS/QFGMOS based current mirror.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Department of Electronics and Communication Engineering
Faculty of Technology
University of Delhi

List of Discipline Specific Elective (DSE)/ Generic Elective (GE) courses offered for Minors/ Specializations by the Department in Fourth Year

1. **Minor in ECE (Offered only to CSE and EE)**
   a) DSE - 6/ GE - 7 : Applied MIMO and B5G Physical Layer Design
   b) DSE - 7/ GE - 8 : Sensors and Actuators for Smart Systems
   c) DSE - 9/ GE - 9 : Statistical Signal Processing
   Or
   Speech and Video Processing
   d) DSE - 10/ GE - 10: Software Defined Radio and Waveform Engineering
   Or
   Compressive Sensing and Sparse Representation

2. **Minor/ Specialization in Telecommunication Networks (Offered to ECE, CSE, and EE)**
   a) DSE - 6/ GE - 7 : Photonic and Optical Communication Networks
   b) DSE - 7/ GE - 8 : Optimization for Engineering
   c) DSE - 9/ GE - 9 : Wireless Systems Implementation
   Or
   Smart Antennas, Beamforming and OTA Testing for 5G/6G
   d) DSE - 10/ GE - 10: Enabling Technologies for 6G Communication
   Or
   Estimation for Wireless Communication

3. **Minor/ Specialization in VLSI Technology and System Design (Offered to ECE, CSE, and EE)**
   a) DSE - 6/ GE - 7 : Microwave Integrated Circuits
   b) DSE - 7/ GE - 8 : Analog VLSI Filter Design
   c) DSE - 9/ GE - 9 : Introduction to Nonlinear Circuits
   Or
   RF Integrated Circuit Design
   d) DSE - 10/ GE - 10: Semiconductor Device Characterization
   Or
   Compact Modeling with Verilog – A

4. **Minor/ Specialization in IoT System Design (Offered to ECE, CSE, and EE)**
   a) DSE - 6/ GE - 7 : Edge IoT Prototyping with RTOS
   b) DSE - 7/ GE - 8 : Industry 4.0 and IIoT
   c) DSE - 9/ GE - 9 : IoT Sensor and Data Integration
   Or
   IoT Reliability Engineering
   d) DSE - 10/ GE - 10: LPWAN IoT Networks
   Or
   Edge Computing

5. Minor/ Specialization in Computer Vision (Offered to ECE, CSE, and EE)

a) DSE - 6/ GE - 7 : Medical Image Processing
b) DSE - 7/ GE - 8 : Remote Sensing and Satellite Image Processing
c) DSE - 9/ GE - 9 : Forensic Image Processing
Or
Computer Graphics
d) DSE - 10/ GE - 10: Computational Photography and Mobile Imaging
Or
Image Restoration and Inpainting

Department of Electronics and Communication Engineering
Faculty of Technology
University of Delhi

Detailed Syllabus of Generic Elective (GE)/ Discipline Specific Elective (DSE) courses offered for Minors/ Specializations by the Department in Semester VII

Applied MIMO and B5G Physical Layer Design (DSE – 6 / GE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Applied MIMO and B5G Physical Layer Design	4	3	0	1	Concepts of Digital Communication Systems

Course Objectives:

- Provides in-depth knowledge of MIMO systems and their importance in Beyond-5G (B5G) physical layer design.
- Teaches advanced MIMO signal processing techniques.
- Covers MIMO channel modeling.
- Includes waveform design for next-generation wireless systems.
- Focuses on beamforming methods for improved performance.
- Introduces emerging PHY-layer techniques for B5G.
- Targets systems enabling: High data rates, Low latency, High reliability in wireless communication.

Course Outcomes:
After completing the course, the students should be able to:

1. Analyze and design MIMO wireless communication systems.
2. Apply advanced beamforming and precoding techniques for B5G systems.
3. Understand PHY-layer challenges in B5G such as high mobility, massive connectivity, and spectrum efficiency.
4. Design and evaluate B5G-enabled waveforms and signal processing techniques.
5. Implement and simulate advanced MIMO and B5G physical layer solutions.

Unit – I **(11 hours)**
Fundamentals of MIMO Systems: Review of wireless channel characteristics and fading, SISO, SIMO, MISO, and MIMO system models, Capacity of MIMO channels, Spatial multiplexing and diversity gains, MIMO channel modeling and correlation, Linear MIMO detection techniques: ZF, MMSE, Introduction to space–time coding (Alamouti scheme).

Unit – II **(12 hours)**
Advanced MIMO and Massive MIMO Techniques: Space–time block codes (STBC) and space–time trellis codes (STTC), Non-linear MIMO detection: SIC, Sphere decoding, Precoding techniques: Eigen-beamforming, linear precoding, Massive MIMO systems and scaling laws, Channel estimation and pilot contamination in massive MIMO, Hardware impairments and practical challenge.

Unit – III **(11 hours)**

B5G Physical Layer Waveforms and Channel Models: Limitations of 5G PHY and motivation for B5G, mmWave and Terahertz communication fundamentals, High-mobility and high-frequency channel models, B5G waveforms: OFDM enhancements, Filter bank multicarrier (FBMC), Universal filtered multicarrier (UFMC), Orthogonal Time Frequency Space (OTFS), Performance comparison of B5G waveforms.

Unit – IV **(11 hours)**

Intelligent PHY and B5G Enabling Technologies: Hybrid and digital beamforming for B5G systems, Beam management and beam tracking, Reconfigurable Intelligent Surfaces (RIS) for PHY enhancement, AI/ML-enabled PHY layer design, Joint communication and sensing (ISAC), Ultra-reliable low-latency communication (URLLC) and massive machine-type communication (mMTC), Future directions toward 6G physical layer.

Essential Readings

1. Fundamentals of Wireless Communication by D. Tse and P. Viswanath (Cambridge University Press)
2. Foundations of MIMO Communication by R. Heath and A. Lozano (Cambridge University Press)
3. MIMO-OFDM Wireless Communications with MATLAB by Y. S. Cho *et al.* (Wiley)

Suggested Readings

1. Wireless Communications by A. Goldsmith (Cambridge University Press)
2. Massive MIMO Networks by E. Björnson *et al.* (NOW Publishers)
3. Millimeter Wave Wireless Communications by T. S. Rappaport, R. W. Heath Jr., R. C. Daniels, and J. N. Murdock (Pearson)
4. Fundamentals of Massive MIMO by Thomas L. Marzetta, Erik G. Larsson, Hong Yang, Hien Quoc Ngo (Cambridge University Press)

List of Experiments (Hardware and Software using Matlab/Simulink – at least 5) **(30 hours)**

1. Simulation and capacity analysis of SISO, SIMO, MISO, and MIMO wireless systems.
2. Performance evaluation of spatial diversity and spatial multiplexing in MIMO channels.
3. Implementation and comparison of linear MIMO detectors (ZF and MMSE).
4. Simulation of non-linear MIMO detection techniques including SIC and sphere decoding.
5. Design and performance analysis of space–time block coding (Alamouti scheme).
6. Simulation of massive MIMO systems and study of pilot contamination effects.
7. Performance analysis of beamforming and precoding techniques for MIMO systems.
8. Implementation and comparison of B5G waveforms (OFDM vs FBMC/UFMC/OTFS).
9. Simulation of mmWave/THz channel models and hybrid beamforming techniques.
10. AI/ML-assisted PHY-layer design for MIMO/B5G systems (e.g., channel estimation or detection).

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Sensors and Actuators for Smart Systems (DSE – 7 / GE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Sensors and Actuators for Smart Systems	4	3	0	1	Concepts of Electrical and Electronics Engineering

Course Objectives:

- To introduce transducers, sensors, and actuators with emphasis on real-world selection and performance parameters.
- To provide working understanding of microfabrication flow and how it relates to microsensors.
- To expose students to important sensor classes including gas sensors, and force / pressure / strain microsensors.
- To build skill in simulation using Multiphysics tool for design / optimization / characterization.
- To develop capability in sensor interfacing.

Course Outcomes:
After completing the course, the students should be able to:

1. Explain operating principles of common sensors/actuators and identify key performance parameters used in evaluation and selection.
2. Describe the microfabrication process flow for microsensors.
3. Use Multiphysics tool to model and optimize a sensor / actuator.
4. Compare gas - sensing approaches and relate choice to application constraints.
5. Interface sensors and implement basic filtering, and perform calibration / characterization.

Unit – I **(11 hours)**
Transducers, Sensors & Performance Parameters: transducers; sensor / actuator classification; static and dynamic characteristics; calibration. Overview of practical sensing mechanisms - resistive / capacitive / piezoelectric / optical / magnetic / MEMS.

Unit – II **(12 hours)**
Microtechnology & Sensor Realization: Thin-film physics, thin film deposition (CVD / PVD), photolithography and patterning, etching methods, MEMS / microsensor structures. Microsensors: force / pressure / strain gauge.

Unit – III **(11 hours)**
Sensor Classes: Gas sensors – optical / MOS / FET, piezoelectric; selection criteria (selectivity, sensitivity, response time, drift). Basics of microfluidics. Actuators: operating principles of piezo / piezoresistive and electrostatic actuation; micropumps and micro-actuators.

Unit – IV **(11 hours)**
Simulation and Characterization: Simulation (Multiphysics), sensitivity, dynamic response; optimization and characterization using EDA. Sensor interfacing with microprocessor / microcontroller.

Essential Readings

1. Handbook of Modern Sensors: Physics, Designs, and Applications by J. Fraden (Springer)
2. An Introduction to the Finite Element Method by J.N. Reddy (McGraw-Hill Education)
3. Advances in Multiphysics Simulation and Experimental Testing of MEMS by Attilio Frangi (Springer)
4. Fundamentals of Microfabrication and Nanotechnology by Marc J. Madou (CRC Press)

Suggested Readings

1. Modeling MEMS and NEMS by Peleshko & Bernstein (CRC Press)
2. The Art of Electronics by Paul Horowitz and Winfield Hill (Cambridge University Press)
3. COMSOL Multiphysics Documentation / Application Library by COMSOL AB (Official Documentation)
4. Microsystem Design by Stephen D. Senturia (Springer)

List of Experiments (Hardware and Software – at least 5) **(30 hours)**

1. To acquire sensor data and determine basic static characteristics with calibration.
2. To control an actuator and implement safe operating limits and stable control logic.
3. To model a mechanical sensor (Multiphysics Simulation) structure and extract sensitivity from simulation results.
4. To simulate a micro actuator principle in a Multiphysics setup.
5. To simulate thermal behaviour and evaluate time constant and sensitivity under heating/cooling.
6. To simulate diffusion/transport behaviour relevant to gas sensing.
7. To model basic microfluidic flow behaviour.
8. To integrate sensors and actuators into a subsystem.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Photonic and Optical Communication Networks (DSE – 6 / GE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	**Tutorial**	**Practical**	
Photonic and Optical Communication Networks	4	3	0	1	NIL

Course Objectives:

- Explain optical transmission techniques for high-speed data transport.
- Develop understanding of the design and operation of modern optical communication networks.
- Emphasize wavelength-based networking concepts (WDM-based systems).
- Introduce optical switching techniques and their role in networking.
- Study different optical network architectures and design principles.
- Explore emerging photonic technologies enabling high-capacity communication systems.

Course Outcomes:
After completing the course, the students should be able to:

1. Understand the fundamentals of photonic and optical communication systems.
2. Analyze optical transmission impairments and system performance.
3. Design wavelength-routed optical networks and optical switching systems.
4. Understand optical network architectures and control mechanisms.
5. Evaluate emerging photonic technologies for future optical networks.

Unit – I **(11 hours)**
Fundamentals of Photonic and Optical Communication: Review of optical fiber communication principles, Optical transmission windows and fiber types, Optical sources and detectors (laser diodes, photodiodes), Optical amplifiers: EDFA, Raman amplifiers, Fiber impairments: attenuation, dispersion, nonlinear effects, System performance parameters and link design basics.

Unit – II **(11 hours)**
Wavelength Division Multiplexing and Optical Switching: Principles of WDM and DWDM systems, Optical multiplexers and demultiplexers, Optical add-drop multiplexers (OADM) and reconfigurable OADMs (ROADM), Optical switching techniques: space, wavelength, and time switching, Optical cross-connects (OXC), Protection and restoration in optical networks.

Unit – III **(12 hours)**
Optical Network Architectures and Control: Optical access networks: PON, FTTH, FTTx, Metropolitan and long-haul optical networks, Wavelength-routed networks and routing and wavelength assignment (RWA), Optical packet switching and optical burst switching, Control and management of optical networks, GMPLS and SDN-enabled optical networks.

Unit – IV **(11 hours)**
Advanced and Emerging Photonic Networks: Elastic optical networks (EON), Coherent optical communication systems, Space-division multiplexing (SDM) and multi-core fibers, Optical wireless and free-space optical (FSO) networks, Photonic integration and silicon photonics, Future trends toward B5G/6G optical networking.

Essential Readings

1. Optical Fiber Communications by G. Keiser (McGraw-Hill)
2. Optical Networks: A Practical Perspective by R. Ramaswami, K. Sivarajan, and G. Sasaki (Morgan Kaufmann)
3. Optical Fiber Communications: Principles and Practice by J. M. Senior and M. Jamro (Pearson)

Suggested Readings

1. Optical Communication Networks by B. Mukherjee (McGraw-Hill)
2. Optical Fiber Telecommunications by I. Kaminow *et al.* (Academic Press)
3. Fiber-Optic Communication Systems by G. P. Agrawal (Wiley)

List of Experiments (Hardware / OptiSystem / OptiSim – at least 5) **(30 hours)**

1. Simulation and analysis of an optical fiber link including attenuation and dispersion effects.
2. Design and performance evaluation of optical transmitters using LED and laser diode sources.
3. Performance analysis of PIN and APD photodiode–based optical receivers.
4. Simulation of optical amplification using EDFA and Raman amplifiers.
5. Design and analysis of WDM/DWDM optical communication systems.
6. Performance evaluation of optical add-drop multiplexers (OADM) and ROADM networks.
7. Simulation of wavelength-routed optical networks and RWA algorithms.
8. Study of protection and restoration schemes in optical networks.
9. Simulation and performance analysis of coherent optical communication systems.
10. Design and evaluation of free-space optical (FSO) communication links under atmospheric effects.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Optimization for Engineering (DSE – 7 / GE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	**Tutorial**	**Practical**	
Optimization for Engineering	4	3	0	1	Concepts of Mathematics - I

Course Objectives:

- To introduce fundamental concepts of numerical optimization.
- To study unconstrained and constrained optimization techniques.
- To understand gradient-based and iterative optimization algorithms.
- To apply numerical optimization methods to engineering problems.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain principles of numerical optimization.
2. Solve unconstrained optimization problems using numerical methods.
3. Apply constrained optimization techniques.
4. Implement optimization algorithms for real-world engineering applications.

Unit – I **(12 hours)**

Basics of Optimization: Optimization problems and applications, classification of optimization problems, convexity, optimality conditions, numerical issues and convergence.

Unit – II **(11 hours)**

Unconstrained Optimization Methods: One-dimensional search methods, gradient descent, steepest descent, Newton's method, quasi-Newton methods, convergence analysis.

Unit – III **(11 hours)**

Constrained Optimization: Equality and inequality constraints, Lagrange multipliers, Karush–Kuhn–Tucker (KKT) conditions, penalty and barrier methods.

Unit – IV **(11 hours)**

Advanced and Practical Optimization Techniques: Nonlinear programming, least squares optimization, stochastic and heuristic methods, applications in signal processing and machine learning.

Essential Readings

1. An Introduction to Optimization by Edwin K. P. Chong and Stanislaw H. Żak (Wiley).
2. Convex Optimization by S. Boyd and L. Vandenberghe (Cambridge University Press)
3. Optimization for Engineering Design by K. Deb (PHI)

Suggested Readings

1. Numerical Optimization by J. Nocedal and S. Wright (Springer)
2. Nonlinear Programming by D. P. Bertsekas (Athena Scientific)

List of Experiments (Hardware / Software) **(30 hours)**

1. Implementation of one-dimensional search methods.
2. Gradient descent and Newton's method for optimization.
3. Constrained optimization using Lagrange multipliers.
4. Implementation of penalty and barrier methods.
5. Least squares optimization problems.
6. Case studies pertaining to Communication Networks using numerical optimization.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Microwave Integrated Circuits (DSE – 6 / GE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Microwave Integrated Circuits	4	3	0	1	Concepts of Electromagnetic Theory / Electromagnetic Field Theory

Course Objectives:

- To introduce microwave IC passive structures and S-parameter based design workflows.
- To design and verify low-noise amplifiers using stability, gain and noise design techniques with practical biasing and matching.
- To design power amplifiers focusing on power/efficiency/linearity metrics and practical output matching (load-pull).
- To design RF switches and integrate LNA–PA–Switch.

Course Outcomes:

After completing the course, the students should be able to:

1. Design microwave passive networks and evaluate performance using S-parameters.
2. Design an LNA and verify stability, gain, noise figure and linearity targets through simulation and layout-aware checks.
3. Design a PA and evaluate P_{sat} / P_{1dB}/IP_3 and efficiency (PAE) with practical matching and stability considerations.
4. Design RF switches and analyze insertion loss, isolation, linearity and power handling trade-offs.
5. Integrate and layout a T/R front-end.

Unit – I **(10 hours)**

Building Blocks: Microstrip/CPW transmission lines, matching, impedance transformation and matching networks, stubs and quarter-wave sections, discontinuities, couplers and power dividers, resonators and basic filter blocks, S-parameters, insertion/return loss.

Unit – II **(12 hours)**

Active Devices and LNA Design: Small-signal models at microwave frequencies, stability circles, gain circles and noise circles, matching for LNA, noise figure, gain trade-offs, linearity metrics, single-stage and two-stage LNA design.

Unit – III **(13 hours)**

Power Amplifier (PA) Design: PA classes, power / compression / efficiency metrics (P_{1dB}, P_{sat}, PAE), load-pull concept and output matching, harmonic, stability under large signal, distortion, thermal / EM considerations.

Unit – IV **(10 hours)**

Switches and T/R: RF switch fundamentals, SPDT switch, T/R switch, LNA + PA + switch + matching, isolation, parasitic management, EM co-simulation, and layout fundamentals.

Essential Readings

1. Microwave Engineering by David M. Pozar (Wiley)
2. Microwave Transistor Amplifiers: Analysis and Design by Guillermo Gonzalez (Prentice Hall)
3. The Design of CMOS Radio-Frequency Integrated Circuits by Thomas H. Lee (Cambridge University Press)
4. RF Power Amplifiers for Wireless Communications by Steve C. Cripps (Artech House)

Suggested Readings

1. RF Microelectronics by Behzad Razavi (Prentice Hall)
2. Microstrip Filters for RF / Microwave Applications by Jia-Sheng Hong and M. J. Lancaster (Wiley)
3. RF Circuit Design: Theory and Applications by Reinhold Ludwig and Pavel Bretchko (Pearson)
4. RF / Microwave Circuit Design for Wireless Applications by Ulrich L. Rohde and David P. Newkirk (Wiley).

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Model transmission lines and basic discontinuities to extract impedance and loss trends across frequency.
2. Design and verify impedance matching networks to meet a target return loss over a given band.
3. Design a passive RF network block and validate key S-parameter performance.
4. Design a basic RF amplifier stage with input/output matching to meet gain and stability goals.
5. Perform stability checks and apply stabilization methods while tracking performance impact.
6. Evaluate amplifier linearity and trade-offs using standard RF metrics and simple design tweaks.
7. Design a basic power stage with output matching and study output power/efficiency behavior.
8. Integrate multiple RF blocks into a simple front-end chain and verify end-to-end performance.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Analog VLSI Filter Design (DSE – 7 / GE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Analog VLSI Filter Design	4	3	0	1	Concepts of Electronic Devices and Circuits / Analog and Digital Electronic Circuits / CMOS Analog IC Design / Current Mode Analog VLSI Circuits

Course Objectives:

- To understand the various filter approximations methods, the frequency scaling, impedance scaling and the various filter transformations.
- To understand the various standard analog filter design approaches.
- To be able to design second order and higher order voltage-mode and current-mode analog filters modern analog electronic circuit building blocks.
- To be able to design fully-integratable Gm-C and OTA-C Filters, MOS Switched-Capacitor Filters and continuous-time MOSFET-C filters.
- To understand the design of log-domain / translinear current-mode (CM) filters.
- To understand the design of CMOS CM square-root domain (SQRD) filters.

Course Outcomes:
After completing the course, the students should be able to:

1. Determine suitable filter function to match the given filter specifications and devise a prototype design.
2. Decide the suitable technology and configuration to be used to design the required filter.
3. Design Gm-C or OTA-C topology and evaluate its performance analytically and experimentally through SPICE simulations.
4. Design a fully-integrable filter using modern analogue circuit building blocks.
5. Design of CMOS compatible Switched-Capacitor or MOSFET-C Filter and justify the choice by using various features.
6. Design a translinear or square root domain filter and verify the design using SPICE simulations

Unit – I **(15 hours)**
Standard analog filter functions, responses; passive RC and RLC filters: first order, second order and higher order; filter approximations: Butterworth, Chebyshev, Inverse Chebyshev; frequency normalization and demoralization; frequency-scaling; impedance-scaling; transformations: LP to HP, LP to BP and LP to BS.

Unit – II **(10 hours)**
Analog filter design: state-variable synthesis of biquad filters, Simulated inductor and FDNR, Filter design using GIC; Leapfrog active ladder filter synthesis to higher order filter design; design of active R inductors, resonators and biquad active filters. CMOS OTAs, transconductors; component simulators using Gm-C and OTA-C, Gm-C inductors, FDNRs; Second order VM and CM biquad designs; higher order Gm-C filter designs.

Unit – III **(10 hours)**
The Current Conveyors, Mixed Translinear Cells (MTL), Translinear realizations of CCII-, CCI+/- and the Controlled Current Conveyor II, Bipolar / CMOS implementations of CCII / CFOAs; internal circuit architectures of modern analog circuit building blocks, Exemplary Universal Voltage-mode and Current-mode filter designs using modern building blocks.

Unit – IV **(10 hours)**
MOS Switched-Capacitor (SC) Filters; SC biquads, higher order SC Filters using bilinear transformation; Techniques of Nonlinearity-cancellation in MOS analog Circuits, MOS Resistive Circuits (MRC); continuous-time MOSFET-C integrators and MOSFET-C filters using CCII and CFOAs; fully-integratable log-domain translinear and CMOS square-root domain (SQRD) filters.

Essential Readings

1. 1. Current-mode VLSI Analog Filters: Design and Applications by P. V. Ananda Mohan (Birkhauser-Boston)
2. Analog Filter Design by M. E. Van Valkenburg and Rolf Schaumann (Holt-Saunders International Edition)
3. Design of Analog Filters: Passive, Active RC and Switched Capacitor by Kenneth Laker, M. S. Ghausi, and Rolf Schumann (Prentice Hall)

Suggested Readings

1. Active and Passive Analog Filter Design: An Introduction by Lawrence P. Huelsman (McGraw-Hill)
2. Active Filter Design by Allan Waters (Macmillan Education)
3. Linear Active Networks: Theory and Design by R. E. Thomas, A. J. Rosa, G. J. Toussaint (Wiley)
4. Analog Filter Design Demystified by Louis E. Frenzel Jr. (McGraw-Hill)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Design of LP, BP and HP Filters using Universal Active Filter (UAF) IC
2. Design of All pass and Notch Filters using Simulated inductors
3. Active-R filter design
4. OTA-C Universal Biquad Filter design
5. Higher order Filter Design using FDNR approach
6. Filter design using active-compensated Tow-Thomas Biquad
7. Switched-Capacitor Filter Design
8. Fully-differential MOSFET-C biquad Filter Design
9. Log-domain and Translinear Filter design
10. Design of a Square-root domain Filter

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Edge IoT Prototyping with RTOS (DSE – 6 / GE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Edge IoT Prototyping with RTOS	4	3	0	1	Introduction to Embedded Systems for IoT

Course Objectives:

- To develop reliable IoT firmware using RTOS building blocks.
- To implement device connectivity and messaging using Wi-Fi / BLE and application messaging using MQTT / HTTP / CoAP.
- To apply practical low-power techniques using sleep modes and duty cycling.
- To design end-to-end edge prototypes integrating sensors, actuators, telemetry, and remote control.

Course Outcomes:

After completing the course, the students should be able to:

1. Develop RTOS-based firmware with multi-task scheduling, IPC, and timing guarantees.
2. Interface sensors and actuators using standard peripherals and build reusable driver modules.
3. Implement robust telemetry and command / control over Wi-Fi / BLE using MQTT / HTTP / CoAP with retries and offline handling.
4. Measure and reduce power consumption using sleep states, wake sources, duty cycling, and current profiling methods.

Unit – I **(12 hours)**

RTOS concepts: tasks / threads, priorities, scheduling and preemption, context switching, semaphores and mutex, message queues, event flags, ISR vs task context, exceptions, interrupts, timers and timer services.

Unit – II **(11 hours)**

Interfacing: interrupts, I2C / SPI / UART basics, ADC sampling patterns and timer-triggered acquisition, debouncing, digital filtering, PWM actuation, storing configuration (EEPROM / Flash / NVS).

Unit – III **(12 hours)**

Connectivity and Messaging: Wi-Fi provisioning and reconnect patterns, BLE GATT services for configuration / telemetry, MQTT publish / subscribe patterns, HTTP / REST and CoAP basics, payload formats (JSON / CBOR).

Unit – IV **(10 hours)**

Low Power and Integration: firmware update concept, rollback, doing more with less (RAM / code / cycles), reducing power consumption, reliability patterns (watchdog), diagnostics (health metrics, last-seen).

Essential Readings

1. Making Embedded Systems: Design Patterns for Great Software by Elecia White (O'Reilly Media)
2. Real-Time Concepts for Embedded Systems by Qing Li and Caroline Yao (CRC Press)
3. Internet of Things: A Hands-On Approach by Arshdeep Bahga and Vijay Madisetti (Universities Press)
4. MQTT Essentials by HiveMQ (HiveMQ)

Suggested Readings

1. Designing Connected Products by Claire Rowland, Elizabeth Goodman, Martin Charlier, Alfred Lui, and Ann Light (O'Reilly Media)
2. Embedded Software Design: A Practical Approach to Architecture, Processes, and Coding Techniques by Jacob Beningo (Elsevier)
3. Advanced PIC Microcontroller Projects in C by Dogan Ibrahim (Newnes)
4. FreeRTOS Documentation, FreeRTOS.org (official docs).

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Develop a basic RTOS based firmware application.
2. Implement event driven input handling using GPIO interrupts.
3. Interface a digital sensor and convert raw data into usable physical values with periodic sampling.
4. Acquire and process analog signals using ADC with simple filtering.
5. Control an actuator output (PWM/GPIO) with timeout / limit behavior.
6. Publish device telemetry over a lightweight messaging protocol.
7. Enable remote control features with command reception and status / acknowledgement responses.
8. Add reliability and power features such as offline buffering/retry and basic low-power duty cycling.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Industry 4.0 and IIoT (DSE – 7 / GE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Industry 4.0 and IIoT	4	3	0	1	Introduction to Embedded Systems for IoT

Course Objectives:

- To introduce the Industry 4.0 vision and how IIoT enables smart factories and smart operations.
- To introduce core building blocks: sensing / actuation, industrial connectivity, and gateways.
- To develop practical understanding of industrial data flow.
- To introduce basic analytics such as monitoring, anomaly detection, predictive maintenance.
- To build awareness of cybersecurity, safety, and reliability requirements in industrial environments.

Course Outcomes:
After completing the course, the students should be able to:

1. Describe Industry 4.0 concepts and identify where IIoT fits in manufacturing automation.
2. Explain an IIoT system architecture using layers.
3. Select suitable industrial connectivity and messaging approaches for common industrial scenarios.
4. Build a basic IIoT data pipeline prototype and interpret key metrics.
5. Apply basic security and reliability practices (identity, authentication, segmentation) for industrial deployments.

Unit – I **(10 hours)**
Industry 4.0 overview: evolution of industrial revolutions, smart factory idea. IIoT fundamentals: sensing & actuation, controllers and gateways, basic communication and networking, data lifecycle. Industrial constraints (uptime, latency, safety, cost).

Unit – II **(12 hours)**
IIoT Architecture: device layer, edge / gateway layer, network layer, platform layer, application layer. Connectivity Options: wired vs wireless, reliability, edge gateway roles. Industrial Protocols: MQTT for telemetry, Modbus basics, REST APIs; integration with SCADA / MES / ERP.

Unit – III **(12 hours)**
Edge vs fog vs cloud roles, local processing and buffering, device management concepts, basic streaming. Industrial data: time-series, event logs, alarms, KPIs. Analytics: descriptive monitoring, simple anomaly detection, and alerting.

Unit – IV **(11 hours)**
Security for IIoT: confidentiality, integrity, availability, safety; identity and authentication, secure communication, access control, network segmentation, logging / monitoring. Reliability: fail-safe behavior, redundancy intuition.

Essential Readings

1. Introduction to Industrial Internet of Things and Industry 4.0 by Sudip Misra, Chandana Roy, and Anandarup Mukherjee (CRC Press)
2. Sensors, Cloud, and Fog: The Enabling Technologies for the Internet of Things by Sudip Misra, Subhadeep Sarkar, Subarna Chatterjee (CRC Press)
3. Industry 4.0: The Industrial Internet of Things by Alasdair Gilchrist (Apress)
4. Practical Industrial Cybersecurity: ICS, Industry 4.0, and IIoT by Charles J. Brooks, Philip A. Craig Jr. (Wiley)

Suggested Readings

1. Introduction to IoT by Sudip Misra, Anandarup Mukherjee, and Arijit Roy (Cambridge University Press)
2. Cybersecurity for Industrial Control Systems: SCADA, DCS, PLC, HMI, and SIS by Tyson Macaulay and Bryan L. Singer (CRC Press)
3. Designing Connected Products by Claire Rowland, Elizabeth Goodman, Martin Charlier, Alfred Lui, and Ann Light (O'Reilly Media)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Acquire or simulate sensor data and produce a clean, timestamped time series stream.
2. Demonstrate a publish / subscribe data flow for telemetry and basic command/control using a simple message format.
3. Model an industrial device communication interface.
4. Implement basic edge processing such as filtering, aggregation, and rate reduction before upstream publishing.
5. Add rule-based alert / event generation and log alarms with timestamps.
6. Run a simple anomaly detection experiment and evaluate detection vs false-alarm behavior.
7. Compare edge vs cloud workflows using basic latency and bandwidth measurements under different streaming modes.
8. Apply basic security controls such as encrypted communication and access control concepts/configuration.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Medical Image Processing (DSE – 6 / GE – 7)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Medical Image Processing	4	3	0	1	Fundamentals of Image Processing, Image Filtering and Restoration

Course Objectives:

- Develop the ability to handle medical image data formats, metadata, and anonymization for safe and reproducible analysis workflows.
- Design and implement medical-image-specific preprocessing and enhancement.
- Build and evaluate segmentation and detection using appropriate clinical metrics and error analysis.
- Perform registration and quantitative measurement extraction.

Course Outcomes:
After completing the course, the students should be able to:

1. Load, visualize and preprocess DICOM / NIfTI and multi-modal datasets.
2. Implement and compare classical and DL segmentation.
3. Perform image registration and evaluate alignment quality.
4. Extract quantitative biomarkers and present results.
5. Design a small end-to-end medical imaging prototype.

Unit – I **(12 hours)**
Medical Imaging Basics: Imaging modalities (X-ray, CT, MRI, Ultrasound). Data formats: DICOM tags, NIfTI volumes, slice spacing, windowing / leveling, anonymization. Dataset preparation: annotation tools, train / val / test splits, class imbalance, augmentation specific to medical images.

Unit – II **(11 hours)**
Preprocessing: Intensity normalization, CLAHE, denoising, deblurring basics, artifact reduction. ROI extraction, body/organ masking, edge-preserving filtering, contrast tuning for X-ray/CT.

Unit – III **(11 hours)**
Segmentation & Detection: Classical segmentation (thresholding, region growing, active contours) and deep segmentation (U-Net / Attention U-Net concepts, patch-based training). Losses (Dice, focal), post-processing (morphology, connected components). Metrics: Dice/IoU, sensitivity/specificity, calibration and confidence visualization.

Unit – IV **(11 hours)**
Registration and 3D Analysis: Rigid / affine registration, similarity measures (SSD / NCC / MI basics), resampling and interpolation. 3D volume processing, extracting measurements (lesion volume, organ size).

Suggested Readings

1. Medical Image Analysis by Atam P. Dhawan (Wiley-IEEE Press)
2. Medical Image Processing, Reconstruction and Restoration: Concepts and Methods by Jiri Jan (CRC Press)
3. Digital Image Processing by Rafael C. Gonzalez and Richard E. Woods (Pearson)
4. Biomedical Image Analysis by Rangaraj M. Rangayyan (CRC Press)

Essential Readings

1. Insight into Images: Principles and Practice for Segmentation, Registration, and Image Analysis by Terry Yoo (A K Peters/CRC Press)
2. The Image Processing Handbook by John C. Russ (CRC Press)
3. Deep Learning for Medical Image Analysis by S. Kevin Zhou, Hayit Greenspan, and Dinggang Shen (Academic Press/Elsevier)

List of Experiments (Software using Matlab / Python) **(30 hours)**

1. To load and visualize DICOM and NIfTI images to extract key metadata.
2. To anonymize a DICOM study safely to verify removal of identifying tags and generate a hashed patient ID mapping.
3. To implement CT windowing / leveling presets to create consistent visualization outputs for reports.
4. To benchmark denoising methods on X-ray/CT images to compare detail preservation using PSNR / SSIM.
5. To build ROI extraction to reduce background clutter and improve downstream model accuracy.
6. To implement classical segmentation to compare against DL segmentation on the same dataset.
7. To train a U-Net style segmentation model on a small labeled dataset to evaluate Dice/IoU and analyze major failure cases.
8. To compare loss functions to study behavior under class imbalance and small lesion sizes.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Remote Sensing and Satellite Image Processing (DSE – 7 / GE – 8)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Remote Sensing and Satellite Image Processing	4	3	0	1	Fundamentals of Image Processing, Image Filtering and Restoration

Course Objectives:

- Develop practical skills to handle satellite raster data using core GIS concepts such as CRS / projections, geo-referencing, clipping, mosaicking, and map layouts.
- Perform standard multispectral preprocessing and generate features.
- Apply SAR processing and interpret SAR backscatter for mapping applications.
- Design and implement classification/segmentation for land cover and object extraction using ML.

Course Outcomes:

After completing the course, the students should be able to:

1. Prepare analysis-ready satellite datasets by applying GIS operations.
2. Generate and interpret multispectral features and use them for mapping tasks.
3. Process SAR imagery using standard steps and create application-specific SAR-derived maps.
4. Train and evaluate supervised classifiers for land-cover mapping using proper sampling, validation splits, and accuracy metrics.

Unit – I **(12 hours)**

Foundations: Remote sensing fundamentals (EM spectrum, sensors, spatial / spectral / temporal resolution, radiometric resolution). GIS basics for imagery: CRS / projections, geo-referencing, resampling, mosaicking, tiling, and spatial extent / scale.

Unit – II **(11 hours)**

Image Preprocessing and Feature Generation: Radiometric / atmospheric correction, cloud / shadow masking, normalization across dates. Band combinations (true / false color) and feature engineering: indices, textures (GLCM), transforms for land-cover separability. Sampling strategy, training label creation.

Unit – III **(11 hours)**

SAR Image Processing: SAR basics, speckle characteristics and filtering (Lee / Frost / Refined Lee), radiometric calibration (Sigma0 / Gamma0 / Beta0), terrain correction / orthorectification, and multi-temporal compositing.

Unit – IV **(11 hours)**

Assessment: Supervised classification, class imbalance, confusion matrix and map accuracy metrics, area estimation. Change detection: index differencing, image ratioing, post-classification comparison, time-series trend basics.

Essential Readings

1. Remote Sensing Digital Image Analysis: An Introduction by John A. Richards and Xiuping Jia (Springer)
2. Remote Sensing of the Environment: An Earth Resource Perspective by John R. Jensen (Pearson)
3. Remote Sensing and Image Interpretation by Thomas M. Lillesand, Ralph W. Kiefer, and Jonathan W. Chipman (Wiley)

Suggested Readings

1. Remote Sensing: Models and Methods for Image Processing by Robert A. Schowengerdt (Academic Press/Elsevier)
2. Synthetic Aperture Radar: Systems and Signal Processing by John C. Curlander and Robert N. McDonough (Wiley-Interscience)

List of Experiments (Software using Matlab / Python – at least 5) **(30 hours)**

1. Create band composites for visual interpretation and validation using reference layers.
2. Perform basic raster preprocessing and observe impact on output quality.
3. Compute common spectral indices and generate thematic maps using simple thresholds.
4. Generate basic texture or auxiliary features to improve separability for baseline analysis.
5. Run a simple supervised classification and evaluate results using standard accuracy metrics.
6. Perform basic change detection between two dates.
7. Process SAR imagery and compare interpretability.
8. Generate a simple SAR based water / flood map and validate qualitatively using available reference data.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Department of Electronics and Communication Engineering
Faculty of Technology
University of Delhi

Detailed Syllabus of Generic Elective (GE)/ Discipline Specific Elective (DSE) courses offered for Minors/ Specializations by the Department in Semester VIII

Statistical Signal Processing (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Statistical Signal Processing	4	3	0	1	Concepts of Signals and Systems, Digital Signal Processing

Course Objectives:
- Provide a strong foundation in probability theory and random processes for signal processing.
- Enable understanding of statistical models of signals and noise.
- Introduce estimation and detection theory for practical signal processing problems.
- Develop the ability to design adaptive and statistical signal processing algorithms.
- Analyze system performance under uncertainty using statistical measures.

Course Outcomes:
After completing the course, the students should be able to:
1. Explain probabilistic concepts and random process models used in statistical signal processing.
2. Apply statistical estimation techniques for parameter extraction from noisy signals.
3. Implement detection and hypothesis testing methods for signal processing applications.
4. Analyse adaptive filtering techniques for time-varying signals.

Unit – I **(11 hours)**
Probability Theory and Random Processes: Review of probability concepts; random variables and probability distributions; expectation, moments, covariance; multiple random variables; random processes; stationarity and ergodicity; autocorrelation and power spectral density; noise models in signal processing.

Unit – II **(12 hours)**
Statistical Estimation Theory: Point and interval estimation; bias, variance, and efficiency; minimum mean square error (MMSE) estimation; maximum likelihood (ML) estimation; Bayesian estimation; Cramér–Rao lower bound; applications to signal parameter estimation.

Unit – III **(11 hours)**
Detection and Hypothesis Testing: Binary and multiple hypothesis testing; Neyman - Pearson criterion; likelihood ratio tests; Bayesian detection; matched filter; signal detection in Gaussian noise.

Unit – IV **(11 hours)**
Adaptive and Advanced Statistical Signal Processing: Adaptive filtering concepts; LMS and RLS algorithms; convergence analysis; spectral estimation methods; Kalman filtering basics; applications in communications, radar, biomedical, and audio signal processing.

Essential Readings

1. Statistical Digital Signal Processing and Modeling by Monson H. Hayes
2. Fundamentals of Statistical Signal Processing, Vol. I (Estimation Theory) & Vol. II (Detection Theory) by S. M. Kay (Pearson)
3. Adaptive Filter Theory by S. Haykin (Pearson)

Suggested Readings

1. Probability, Random Variables, and Stochastic Processes by A. Papoulis and S. U. Pillai (McGraw-Hill)
2. Detection, Estimation, and Modulation Theory by H. L. Van Trees (Wiley)
3. An Introduction to Statistical Signal Processing by R. M. Gray and L. D. Davisson (Cambridge University Press)

List of Experiments (Hardware / Software using Matlab / Simulink – at least 5) **(30 hours)**

1. Simulation of random variables and probability distributions.
2. Generation and analysis of random processes.
3. Statistical characterization of noise signals.
4. Parameter estimation using ML and MMSE techniques.
5. Binary hypothesis testing and ROC curve analysis.
6. Matched filter implementation for signal detection.
7. Adaptive filtering using LMS algorithm.
8. Adaptive filtering using RLS algorithm.
9. Spectral estimation of random signals.
10. Mini-project on a statistical signal processing application.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Speech and Video Processing (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Speech and Video Processing	4	3	0	1	Concepts of Signals and Systems

Course Objectives:

- Understand the fundamentals of speech and video signal processing.
- Analyze speech production, perception, and representation techniques.
- Apply digital video processing methods for enhancement and analysis.
- Design algorithms for speech and video coding, recognition, and analysis.
- Evaluate speech and video processing systems for real-world multimedia applications.

Course Outcomes:
After completing the course, the students should be able to:

1. Explain speech and video signal characteristics and representation methods.
2. Apply speech analysis techniques for feature extraction and enhancement.
3. Implement video processing techniques including motion estimation and compression.
4. Analyze speech and video coding and recognition algorithms.
5. Design and evaluate speech and video processing solutions for multimedia applications.

Unit – I **(11 hours)**
Speech production and perception mechanism; speech signal characteristics; sampling and quantization of speech signals; short-time analysis; time-domain and frequency-domain representations; speech databases.

Unit – II **(12 hours)**
Linear predictive coding (LPC); cepstral analysis; Mel-frequency cepstral coefficients (MFCC); speech enhancement techniques; speech coding standards; speech recognition and synthesis overview.

Unit – III **(11 hours)**
Video signal representation; color models and spaces; human visual system; spatial and temporal redundancy; video sampling and formats; basic video enhancement techniques.

Unit – IV **(11 hours)**
Motion estimation and compensation; transform coding; video compression standards (MPEG, H.264/AVC, HEVC); video segmentation and object tracking; applications in surveillance, multimedia, and communication.

Essential Readings

1. Digital Processing of Speech Signals by L. R. Rabiner and R. W. Schafer (Pearson)
2. Discrete-Time Processing of Speech Signals by J. R. Deller, J. H. L. Hansen, and J. G. Proakis (IEEE Press)
3. Digital Video Processing by A. Murat Tekalp (Prentice Hall)

Suggested Readings

1. Multimedia Communication Systems by K. R. Rao, Z. S. Bojkovic, and D. A. Milovanovic (Prentice Hall)
2. Digital Image Processing by R. C. Gonzalez and R. E. Woods (Pearson)

List of Experiments (Hardware / Software using Matlab / Simulink – at least 5) **(30 hours)**

1. Speech signal acquisition and visualization.
2. Time-domain and frequency-domain analysis of speech signals.
3. Speech feature extraction using LPC and MFCC.
4. Speech enhancement using filtering techniques.
5. Speech coding and compression experiment.
6. Video frame extraction and color space conversion.
7. Video enhancement using spatial filtering.
8. Motion estimation and motion compensation.
9. Video compression using MPEG/H.264 standards.
10. Mini-project on speech or video processing application.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Software Defined Radio and Waveform Engineering (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Software Defined Radio and Waveform Engineering	4	3	0	1	Concepts of Signals and Systems / Digital Signal Processing

Course Objectives:

- Introduce SDR fundamentals and I/Q signal concepts.
- Implement basic receivers/transmitters using block-based tools (GNU Radio).
- Learn debugging using spectrum / constellation / time plots.
- Develop practical ability to build basic SDR receiver chains (tuning, filtering, demodulation).
- Train students to handle real-world impairments (noise, CFO, timing offset, interference).

Course Outcomes:

After completing the course, the students should be able to:

1. Configure SDR hardware / software and correctly capture, visualize, and interpret I/Q signals in time and frequency domains.
2. Design and implement basic modulation / demodulation (AM / FM / FSK and BPSK / QPSK) using SDR tools.
3. Apply practical synchronization methods (preamble / correlation, CFO correction) and improve receiver robustness.
4. Evaluate waveform performance using simple KPIs (spectrum, constellation, BER/PER trends) and justify parameter choices.

Unit – I **(10 hours)**

SDR concept and architecture, I/Q representation and complex signals, sampling rate / aliasing, gain staging and dynamic range, time / frequency visualization (FFT), SDR using GNU Radio / MATLAB.

Unit – II **(12 hours)**

Digital mixing and frequency translation, FIR filtering, decimation / interpolation and resampling, windowing and PSD estimation, AGC, DC offset / IQ imbalance.

Unit – III **(12 hours)**

AM / FM receiver chain, FSK / GFSK for telemetry / IoT, BPSK / QPSK (constellation view), pulse shaping (RRC), symbol rate vs sample rate planning, constellation / eye diagram interpretation and tuning knobs.

Unit – IV **(11 hours)**

Noise and SNR, frequency offset and phase noise, timing offset and symbol timing recovery, preamble-based synchronization, equalization, interference and adjacent channel issues, robustness: oversampling, filtering, thresholds, retry framing.

Essential Readings

1. Software Defined Radio using MATLAB & Simulink and the RTL-SDR by Robert W. Stewart (Strathclyde Academic Media)
2. Understanding Digital Signal Processing by Richard G. Lyons (Pearson)
3. Digital Communications: Fundamentals and Applications by Bernard Sklar (Pearson)
4. GNU Radio Tutorial Available at: https://wiki.gnuradio.org/index.php/Tutorials

Suggested Readings

1. Software Defined Radio for Engineers by Travis F. Collings, Robin Getz, Di Pu, and Alexander M. Wyglinski (Artech House)
2. Communication Systems by Simon Haykin (Wiley)
3. Signals and Systems by Alan V. Oppenheim and Alan S. Willsky (Pearson)

List of Experiments (Hardware / Software using Matlab / Simulink – at least 5) **(30 hours)**

1. Set up an SDR receiver and verify basic operations.
2. Capture and replay I/Q samples and compare time/frequency-domain behavior offline.
3. Build a basic analog demod receiver and validate recovered audio / signal quality.
4. Implement frequency translation and channel filtering for a selected channel.
5. Implement a simple digital demod chain and recover a stable data stream.
6. Simulate digital modulation (BPSK/QPSK) and study constellation behavior under noise.
7. Implement basic packet detection / framing using a preamble / correlation approach.
8. Evaluate link performance and robustness via BER/PER and simple interference mitigation.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Compressive Sensing and Sparse Representation (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Compressive Sensing and Sparse Representation	4	3	0	1	Concepts of Signals and Systems / Mathematics - I

Course Objectives:

- To introduce the principles of sparsity and compressive sensing.
- To understand sparse signal models and reconstruction algorithms.
- To analyze theoretical guarantees for sparse recovery.
- To apply compressive sensing techniques to signal and image processing problems.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain sparsity and compressive sensing fundamentals.
2. Apply sparse representation models to signals.
3. Implement reconstruction algorithms for compressive sensing.
4. Solve practical signal processing problems using CS techniques.

Unit – I **(11 hours)**
Introduction to Compressive Sensing: Motivation for compressive sensing, sparsity and redundancy, sparse signal models, Nyquist sampling limitations, incoherence, measurement matrices.

Unit – II **(12 hours)**
Sparse Representation and Dictionaries: Orthonormal bases, overcomplete dictionaries, dictionary learning, matching pursuit and orthogonal matching pursuit algorithms.

Unit – III **(11 hours)**
Signal Recovery Algorithms Basis pursuit, LASSO, greedy algorithms, convex optimization methods, restricted isometry property (RIP), performance guarantees.

Unit – IV **(11 hours)**
Applications of Compressive Sensing: Compressive sensing in image processing, wireless communications, biomedical signals, radar and sensor networks, recent research trends.

Essential Readings

1. Sparse and Redundant Representations by M. Elad (Springer)
2. Introduction to Linear Algebra by G. Strang (Wellesley-Cambridge Press)
3. A Mathematical Introduction to Compressive Sensing by S. Foucart and H. Rauhut (Birkhäuser).

Suggested Readings

1. An Introduction to Compressive Sampling by E. J. Candès and M. B. Wakin (IEEE Signal Processing Magazine)
2. A Wavelet Tour of Signal Processing by S. Mallat (Academic Press)
3. Compressive Sensing by R. Baraniuk (IEEE Signal Processing Magazine)
4. Sparse and Redundant Representations by M. Elad (Springer)

List of Experiments (Hardware / Software using Matlab / Simulink) **(30 hours)**

1. Verification of sparsity in time and transform domains.
2. Implementation of random measurement matrices.
3. Signal reconstruction using Basis Pursuit.
4. Sparse recovery using Matching Pursuit and OMP.
5. Image reconstruction using compressive sensing.
6. Performance comparison of sparse recovery algorithms.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Wireless System Implementation (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Wireless System Implementation	4	3	0	1	Concepts of Digital Communication Systems, Optical and Wireless Communication

Course Objectives:

- To enable students to design and implement a basic wireless communication system.
- To introduce large-scale wireless propagation models and their role in system design.
- To develop understanding of wireless channel modeling as a linear time-varying (LTV) filter.
- To study statistical multipath channel models used in practical wireless environments.
- To teach digital modulation and demodulation techniques used in wireless communication systems.
- To analyze the performance of digital modulation schemes over Rayleigh fading channels.
- To understand and evaluate spatial diversity techniques for improving reliability.
- To compare single-carrier vs multicarrier (OFDM) modulation, highlighting key trade-offs.
- To provide hands-on experience through a MATLAB + NI USRP based project to validate theoretical concepts experimentally.

Course Outcomes:

After completing the course, the students should be able to:

1. Students are able to analyze the behavior of large scale and small scale wireless propagation models.
2. Students are able to simulate the performance (in Matlab, GNU Radio, LabVIEW) of a wireless communication system in various channel conditions.
3. Students are able to analyze the benefits of multicarrier systems over single carrier systems.
4. Students are able to design and implement a basic wireless communication system using software such as Matlab, GNU Radio or LabVIEW

Unit – I **(11 hours)**

Wireless Propagation and Channel Modeling: Introduction to wireless communication systems, Large-scale propagation models: free-space, two-ray ground reflection, log-distance model, Shadowing effects and path loss estimation, Wireless channel as a linear time-varying (LTV) system, Delay spread, Doppler spread, coherence bandwidth, coherence time, Introduction to multipath propagation

Unit – II **(09 hours)**

Statistical Multipath Fading Models: Small-scale fading mechanisms, Statistical channel models: Rayleigh, Rician, and Nakagami fading, Time-selective and frequency-selective fading, Doppler spectrum and mobility effects, Channel characterization and simulation using MATLAB.

Unit – III **(12 hours)**

Digital Modulation and Diversity Techniques: Digital modulation and demodulation schemes: BPSK, QPSK, M-PSK, M-QAM, BER performance analysis in AWGN and Rayleigh fading channels, Impact of fading on digital communication systems, Spatial diversity techniques: Selection combining, Maximal ratio combining (MRC), Equal gain combining, Performance comparison with and without diversity.

Unit – IV **(13 hours)**
Multicarrier Systems and Practical Implementation: Single-carrier vs multicarrier transmission: trade-offs and design challenges, Introduction to multicarrier modulation, Orthogonal Frequency Division Multiplexing (OFDM): principles and advantages, OFDM system model, cyclic prefix, and PAPR issues, Performance comparison of single-carrier and OFDM systems in fading channels
Course project: MATLAB-based simulation of wireless systems or Hardware/software implementation using NI USRP to validate theoretical concepts

Essential Readings

1. Wireless Communications and Applications Above 100 GHz by T. S. Rappaport *et al.* (IEEE Access)
2. Wireless Communications by A. Goldsmith (Cambridge University Press)
3. Introduction to Wireless Digital Communication: A Signal Processing Perspective by Robert W. Heath Jr. and Jeffrey G. Andrews (Pearson)

Suggested Readings

1. Wireless Communication Systems: From RF Subsystems to 4G Enabling Technologies by Ke – Lin Du, and M. N. S. Swamy (Cambridge University Press)
2. Principles of Mobile Communication by Gordon L. Stuber (Springer)
3. Digital Communications by John G. Proakis and Masoud Salehi (McGraw-Hill)

List of Experiments (Hardware / Software using Matlab / Simulink – at least 5) **(30 hours)**

1. Study and simulation of large-scale path loss and shadowing models in wireless channels.
2. Modeling of wireless channel as a linear time-varying system and analysis of delay and Doppler spread.
3. Simulation of Rayleigh and Rician fading channels and statistical characterization.
4. BER performance analysis of BPSK and QPSK modulation over AWGN and Rayleigh fading channels.
5. Performance evaluation of M-PSK and M-QAM schemes in fading environments.
6. Study and implementation of spatial diversity techniques (Selection Combining and MRC).
7. Performance comparison of single-antenna and diversity-based wireless systems.
8. Simulation and analysis of OFDM systems including cyclic prefix and PAPR effects.
9. Performance comparison of single-carrier and OFDM systems over multipath fading channels.
10. MATLAB/NI-USRP–based implementation and validation of a basic wireless communication link.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Smart Antennas, Beamforming and OTA Testing for 5G/6G (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Smart Antennas, Beamforming and OTA Testing for 5G/6G	4	3	0	1	Concepts of Electromagnetic Theory

Course Objectives:

- To introduce the fundamentals of smart antennas and beamforming techniques used in 5G and 6G systems.
- To develop understanding of antenna arrays and adaptive beamforming algorithms.
- To study massive MIMO and advanced antenna technologies including metasurfaces.
- To familiarize students with OTA testing methodologies and industry standards.
- To provide practical exposure through simulation and measurement-based experiments.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain smart antenna concepts and wireless propagation characteristics for 5G/6G.
2. Analyze and design antenna arrays and beamforming architectures.
3. Apply adaptive and hybrid beamforming algorithms to wireless scenarios.
4. Understand massive MIMO, metasurface and RIS-based antenna systems.
5. Perform OTA testing and interpret standard performance metrics.
6. Use modern RF simulation and measurement tools effectively.

Unit – I **(10 hours)**

Introduction to smart antenna systems and their evolution, limitations of conventional antennas, adaptive and intelligent antenna concepts, advantages in spectral efficiency, coverage and interference suppression, beam steering and beam shaping, spatial diversity and spatial multiplexing, wireless propagation characteristics for sub-6 GHz, mmWave and sub-THz bands.

Unit – II **(12 hours)**

Principles of beamforming and spatial filtering, analog, digital and hybrid beamforming architectures, phase shifter-based and true time delay beamforming, adaptive beamforming concepts, classical algorithms including delay-and-sum, LMS, RLS and MVDR, beam training and beam tracking in 5G NR, codebook-based beamforming.

Unit – III **(11 hours)**

3D beamforming, antenna design challenges for sub-6 GHz and mmWave frequencies, compact wideband antenna arrays, polarization diversity and circular polarization, metasurface-based antennas and reconfigurable intelligent surfaces (RIS), integration issues in base stations and user equipment for 5G and future 6G systems.

Unit – IV **(12 hours)**
Need for OTA testing in modern wireless systems, conducted versus OTA measurements, OTA test environments including anechoic and reverberation chambers, near-field and far-field measurement techniques, compact antenna test ranges, mmWave OTA challenges and calibration of phased arrays, 3GPP OTA standards for 5G NR, emerging OTA requirements for 6G and intelligent radio environments.

Essential Readings

1. Smart Antennas by L. C. Godara (CRC Press)
2. Antenna Theory: Analysis and Design by C. A. Balanis (Wiley)
3. Millimeter Wave Wireless Communications by T. S. Rappaport *et al.* (Pearson)
4. 3GPP TS 38 Series: 5G New Radio Specifications by 3GPP (3GPP)

Suggested Readings

1. Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency by Emil Björnson and Jakob Hoydis (Now Publishers)
2. Fundamentals of Wireless Communication by David Tse and Pramod Viswanath (Cambridge University Press)
3. Phased Array Antenna Handbook by Robert J. Mailloux (Artech House)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Simulation of radiation pattern and array factor of linear antenna arrays.
2. Beam steering and beamwidth analysis of planar antenna arrays.
3. Design and simulation of phased array antennas for sub-6 GHz 5G applications.
4. Analog beamforming using phase shifter-based networks.
5. Digital beamforming implementation using MATLAB.
6. Adaptive beamforming using LMS algorithm.
7. Performance evaluation of MVDR beamforming algorithm.
8. Hybrid beamforming simulation for mmWave 5G systems.
9. Massive MIMO channel modeling and capacity analysis.
10. Design and analysis of compact mmWave antenna arrays.
11. Polarization diversity and circularly polarized antenna array analysis.
12. Metasurface or RIS-based beam control and reconfiguration simulation.
13. Near-field and far-field antenna measurement techniques.
14. OTA measurement of EIRP, TRP and beam patterns.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Enabling Technologies for 6G Communication (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Enabling Technologies for 6G Communication	4	3	0	1	Concepts of Digital Communication Systems, Optical and Wireless Communication

Course Objectives:

- Introduce the vision, requirements, and key performance indicators (KPIs) of 6G wireless communication systems.
- Provide in-depth knowledge of enabling technologies such as THz communication, massive MIMO, AI/ML, RIS, and ultra-low latency networks.
- Explain the role of non-terrestrial networks (NTNs) in future 6G architectures.
- Enable students to analyze CubeSat communication systems, link budgets, and their integration with terrestrial and aerial networks.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain the vision, architecture, and performance requirements of 6G communication systems.
2. Analyze key 6G enabling technologies such as THz bands, massive MIMO, AI-driven networking, and reconfigurable intelligent surfaces.
3. Describe CubeSat systems and communication architectures, including payloads, orbits, and inter-satellite links.
4. Perform basic link budget and performance analysis for CubeSat-based communication systems.
5. Evaluate the integration of CubeSats with 6G terrestrial, aerial (UAV), and non-terrestrial networks for future applications.

Unit – I **(11 hours)**

Introduction to 6G Communication Systems: Evolution from 1G to 6G, Limitations of 5G and motivation for 6G, Vision and KPIs of 6G (Tbps data rates, µs latency, extreme reliability, sustainability), 6G use cases: holographic communication, tactile internet, digital twins, smart cities, 6G network architecture overview, Space–Air–Ground–Sea Integrated Networks (SAGSIN).

Unit – II **(11 hours)**

Enabling Technologies for 6G: Terahertz (THz) communication: spectrum, challenges, channel modelling, Massive MIMO and cell-free MIMO, Reconfigurable Intelligent Surfaces (RIS), AI/ML for 6G: intelligent resource allocation, self-organizing networks, Ultra-low latency and ultra-reliable communication, Energy-efficient and green 6G technologies.

Unit – III **(12 hours)**

CubeSat Systems and Communication Fundamentals: Introduction to CubeSats and small satellites, CubeSat standards and form factors (1U, 3U, 6U, 12U), CubeSat subsystems: structure, power, ADCS, payload, communication, Orbits and coverage (LEO, constellation concepts), CubeSat communication links: Uplink, downlink, inter-satellite links (ISL), Frequency bands (VHF/UHF, S-band, X-band, Ka-band), CubeSat link budget fundamentals

Unit – IV **(11 hours)**

CubeSats in 6G and Future Research Directions: Role of CubeSats in 6G Non-Terrestrial Networks (NTN), Integration of CubeSats with terrestrial, UAV, and HAPS networks, CubeSat-enabled IoT, remote sensing, disaster management, and global connectivity, Challenges: mobility, Doppler, latency, spectrum sharing, security, 6G-enabled CubeSat communication use cases, Open research problems and future trends in 6G-NTN systems

Essential Readings

1. 6G Enabling Technologies: New Dimensions to Wireless Communication by Ramjee Prasad *et al.* (River Publishers / CRC Press)
2. 6G-Enabled Technologies for Next Generation by Amit Kumar Tyagi *et al.* (Wiley)
3. The Road towards 6G: Opportunities, Challenges, and Applications by Valeria Loscri *et al.* (Springer)

Suggested Readings

1. A Vision of 6G Wireless Systems by W. Saad, M. Bennis, and M. Chen (IEEE)
2. What Will 6G Be? by J. G. Andrews *et al*. (IEEE Journal on Selected Areas in Communications)
3. CubeSat Handbook by R. Twiggs and J. Puig-Suari (Academic Press)

List of Experiments (MATLAB / Simulink, STK (optional), Python, NS-3 – at least 5) **(30 hours)**

1. Study of 6G Vision and KPIs
   Analyze key performance indicators of 6G (data rate, latency, reliability, energy efficiency) and compare them with 5G.
2. Path Loss and Channel Modeling for mmWave and THz Bands
   Simulate free-space and atmospheric attenuation models for mmWave/THz frequencies used in 6G.
3. Massive MIMO Performance Analysis
   Evaluate beamforming gain, capacity, and spectral efficiency in massive MIMO systems.
4. Reconfigurable Intelligent Surface (RIS) Assisted Communication
   Simulate RIS-assisted links and analyze SNR and capacity improvement.
5. AI/ML-Based Resource Allocation for 6G Networks
   Implement a simple ML algorithm for power or bandwidth allocation in a 6G-like network scenario.
6. CubeSat Orbit and Coverage Analysis
   Study LEO CubeSat orbits, ground coverage, and revisit time using analytical models or simulation tools.
7. CubeSat Link Budget Calculation
   Compute uplink and downlink link budgets for CubeSat communication in different frequency bands.
8. Doppler Shift and Mobility Effects in CubeSat Communication
   Analyze Doppler effects due to CubeSat mobility and their impact on signal quality.
9. Integration of CubeSat with Terrestrial 6G Network (NTN Scenario)
   Model a basic non-terrestrial network scenario integrating CubeSat and ground users.
10. Mini Project: 6G-Enabled CubeSat Communication System
    Design and simulate a small 6G-NTN use case (IoT via CubeSat, disaster connectivity, or remote sensing).

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Estimation for Wireless Communication (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	**Tutorial**	**Practical**	
Estimation for Wireless Communication	4	3	0	1	Concepts of Signals and Systems, Digital Communication Systems, Optical and Wireless Communication

Course Objectives:

- Introduce statistical estimation theory and its importance in wireless communication systems.
- Enable students to understand and apply parameter estimation techniques used in digital and wireless receivers.
- Provide knowledge of channel estimation, synchronization, and detection in fading and noisy wireless channels.
- Expose learners to modern estimation methods used in MIMO, OFDM, and emerging wireless systems.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain the fundamentals of random processes, noise, and estimation theory used in wireless communications.
2. Apply classical estimation techniques such as LS, ML, and MMSE for parameter estimation.
3. Analyze channel estimation and synchronization techniques in wireless systems.
4. Design and evaluate estimation algorithms for modern wireless systems such as OFDM and MIMO.

Unit – I **(12 hours)**

Fundamentals of Estimation Theory: Review of probability and random variables, Random processes and noise models, Parameter estimation problem formulation, Bias, variance, mean square error (MSE), Cramér–Rao Lower Bound (CRLB), Bayesian vs non-Bayesian estimation.

Unit – II **(11 hours)**

Classical Estimation Techniques: Least Squares (LS) estimation, Weighted Least Squares (WLS), Maximum Likelihood (ML) estimation, Minimum Mean Square Error (MMSE) estimation, Linear and nonlinear estimators, Performance comparison of estimators

Unit – III **(11 hours)**

Estimation in Wireless Communication Systems: Channel estimation in AWGN and fading channels, Pilot-based channel estimation, Frequency and phase offset estimation, Timing synchronization, Estimation in OFDM systems, Doppler estimation in mobile channels.

Unit – IV **(11 hours)**

Advanced Estimation Techniques: Estimation in MIMO systems, Adaptive filtering and LMS/RLS algorithms, Kalman filtering for wireless tracking, Sparse channel estimation, Estimation challenges in 5G/6G systems, Introduction to machine learning-based estimation.

Essential Readings

1. An Introduction to Signal Detection and Estimation by H. Vincent Poor (Springer)
2. Fundamentals of Statistical Signal Processing, Vol. I: Estimation Theory by Steven M. Kay (Pearson)
3. Adaptive Filter Theory by Simon Haykin (Pearson)

Suggested Readings

1. Detection, Estimation, and Modulation Theory, Part I by Harry L. Van Trees (Wiley)
2. Statistical Signal Processing: Detection, Estimation, and Time Series Analysis by Louis L. Scharf (Addison-Wesley)
3. Fundamentals of Statistical Signal Processing, Vol. II: Detection Theory by Steven M. Kay (Pearson)

List of Experiments (MATLAB / Simulink / Python – at least 5) **(30 hours)**

1. Path Loss and Channel Modeling for mmWave and THz Band
   Simulation of Random Variables and Noise Models
2. Generate Gaussian noise and analyze statistical properties.
   Performance Analysis of Estimators
3. Evaluate bias, variance, and MSE for simple estimators.
4. Least Squares (LS) Estimation
   Implement LS estimation and study its performance.
5. Maximum Likelihood (ML) Estimation
   Implement ML estimator for unknown signal parameters.
6. MMSE Estimation
   Compare MMSE estimator with LS and ML estimators.
7. Channel Estimation in AWGN Channel
   Estimate channel coefficients using pilot symbols.
8. Channel Estimation in Fading Channel
   Analyze estimation performance in Rayleigh fading.
9. OFDM Channel Estimation
   Implement pilot-based channel estimation in OFDM systems.
10. Adaptive Filtering Using LMS Algorithm
    Implement LMS algorithm and analyze convergence behavior.
11. Kalman Filter for Wireless Parameter Tracking
    Track time-varying channel or frequency offset.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Introduction to Nonlinear Circuits (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Introduction to Nonlinear Circuits	4	3	0	1	Introduction to Electrical and Electronics Engineering, Concepts of Signals and Systems

Course Objectives:

- To analyse nonlinear behavior in circuits such as saturation, hysteresis, switching, bifurcations, and chaos.
- To analyze first/second-order nonlinear dynamics using state equations and phase portraits.
- To connect nonlinear theory to: oscillators, Schmitt triggers / comparators, PLL.
- To understand oscillators as nonlinear systems and study amplitude stabilization.
- Realize nonlinear elements using op-amps/OTAs/CFOAs and impedance-synthesis blocks (NIC/GIC).
- To connect nonlinear theory to switching, triggering, memory circuits, and oscillators.

Course Outcomes:

After completing the course, the students should be able to:

1. Identify sources of nonlinearity in real circuits (device IV, saturation, switching, feedback limits) and explain their impact on behavior.
2. Build nonlinear circuit models using diode / BJT / MOS large-signal elements.
3. Derive state equations for 1-2 state nonlinear circuits and compute / locate equilibrium points and operating regions.
4. Detect and characterize limit cycles in simulation and relate them to oscillator startup and steady-state amplitude.
5. Apply describing-function intuition to estimate oscillation possibility/amplitude.
6. Produce bifurcation style plots using parameter sweeps and recognize period doubling /route-to-chaos signatures in waveforms and spectra.

Unit – I **(10 hours)**

Basics: sources of nonlinearity (device IV, saturation, switching), piecewise-linear / behavioral models, operating regions, linearization. Energy-storage elements (C, L), memristor concept. Realization basics: op-amp/OTA/CFOA as nonlinear blocks and NIC/GIC idea for impedance / nonlinear element emulation.

Unit – II **(12 hours)**

State-space and phase-plane tools: state equations for simple nonlinear RC/RLC circuits, nullclines, equilibrium classification, Lyapunov-style, limit cycles and oscillations, function for predicting oscillation / amplitude. Realization: nonlinear function block (PWL/saturation).

Unit – III **(11 hours)**

Nonlinear oscillators: Van der Pol / Duffing, amplitude stabilization, waveform shaping, Schmitt trigger relaxation oscillators, PLL nonlinearity (pull-in / lock range idea), effect of saturation / clipping on spectra and distortion.

Unit – IV **(12 hours)**
Bifurcations and chaos: period-doubling, routes to chaos, Chua-type circuit and double: scroll attractor, jerk circuit using integrators, memristor - emulator based chaos (NIC / GIC), Poincaré section, parameter sweeps and bifurcation diagrams.

Essential Readings

1. Linear and Nonlinear Circuits by Leon O. Chua, Charles A. Desoer, Ernest S. Kuh (McGraw-Hill)
2. Nonlinear Dynamics and Chaos by Steven H. Strogatz (Westview Press)
3. Chaos in Circuits and Systems by Guanrong Chen and Tetsushi Ueta (World Scientific)
4. Analysis and Design of Analog Integrated Circuits by Paul R. Gray, Paul J. Hurst, Stephen H. Lewis, Robert G. Meyer (Wiley)

Suggested Readings

1. RF Microelectronics by Behzad Razavi (Pearson)
2. Nonlinear Systems by Hassan K. Khalil (Pearson)
3. Synchronization: A Universal Concept in Nonlinear Sciences by Arkady Pikovsky, Michael Rosenblum, Jurgen Kurths (Cambridge University Press)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. To simulate a diode clipper / limiter in time-domain to observe waveform clipping and quantify harmonic distortion using FFT.
2. To implement a Van der Pol type oscillator to verify limit-cycle formation and amplitude stabilization from different initial conditions.
3. To simulate a Duffing oscillator under periodic forcing to demonstrate hysteresis/jump phenomenon by sweeping the drive frequency up and down.
4. To apply describing-function style prediction to a nonlinear amplifier and linear filter loop to estimate oscillation condition/amplitude and validate in simulation.
5. To build a Chua-like nonlinear oscillator model to capture chaotic signatures using phase portraits and time series plots.
6. To run a parameter sweep on a nonlinear oscillator coefficient (gain/nonlinearity) to generate a bifurcation-style plot and identify period changes.
7. To perform Poincaré sampling of a periodically forced nonlinear system to construct a Poincaré map and interpret periodic vs chaotic behavior.
8. To build a memristor emulator using NIC/GIC concepts (behavioral or op-amp implementation) to verify pinched hysteresis and explore memristive chaos.
9. To implement a jerk circuit to generate chaotic attractors.
10. To implement an OTA-based voltage-controlled resistor (VCR) / nonlinear transconductor to demonstrate controllable damping/negative resistance in a dynamic circuit.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

RF Integrated Circuit Design (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
RF Integrated Circuit Design	4	3	0	1	Concepts of Electromagnetic Theory / Microwave Integrated Circuits

Course Objectives:

- To introduce a practical RFIC design flow.
- To design core RFIC receiver blocks with noise / linearity studies.
- To design LC VCOs and PLL-based frequency synthesizers and relate phase noise/jitter to system performance.
- To learn RFIC layout practices and post-layout correlation.

Course Outcomes:

After completing the course, the students should be able to:

1. Translate RF transceiver requirements into block-level targets using gain / noise / linearity budgets.
2. Design and verify mixers / VGAs / baseband filters and evaluate conversion gain, NF, IIP3, and LO leakage trends.
3. Design an LC VCO and PLL synthesizer, and evaluate phase noise/jitter impact on receiver/transmitter performance.
4. Apply RFIC layout techniques for passives and sensitive nodes.

Unit – I **(10 hours)**

RFIC System: RFIC vs MIC (substrate loss, parasitics, Q, coupling), compact RF models, passives (spiral L, MIM C, varactors, resistors), floorplanning and isolation (guard rings, shielding, differential routing).

Unit – II **(12 hours)**

Receiver IC Blocks: direct-conversion/low-IF comparison, mixers (passive/active), Metrics: conversion gain / loss, NF, IIP3, isolation, LO feedthrough), VGAs and AGC concept, baseband filtering (active-RC / Gm-C), DC offset and flicker-noise.

Unit – III **(12 hours)**

Frequency Synthesis and LO Generation: LC VCO design, phase noise, LO buffers, quadrature LO generation, PLL blocks and lock behavior.

Unit – IV **(11 hours)**

RFIC Integration: Layout (passive placement, routing parasitics, substrate coupling, supply/ground noise), EM simulation, corner / Monte-Carlo robustness checks, stability / oscillation checks for RF blocks.

Essential Readings

1. RF Microelectronics by Behzad Razavi (Pearson)
2. The Design of CMOS Radio-Frequency Integrated Circuits by Thomas H. Lee (Cambridge University Press)
3. Phase-Locked Loops: Design, Simulation, and Applications by Roland E. Best (McGraw-Hill)
4. CMOS Integrated Circuit Design by Paul R. Gray, Paul J. Hurst, Stephen H. Lewis, and Robert G. Meyer (Wiley)

Suggested Readings

1. Microwave Transistor Amplifiers: Analysis and Design by Guillermo Gonzalez (Pearson)
2. RF Circuit Design: Theory and Applications by Reinhold Ludwig and Pavel Bretchko (Pearson)
3. RF Power Amplifiers for Wireless Communications by Steve C. Cripps (Artech House)

List of Experiments (Hardware / Software) **(30 hours)**

1. To model on chip passives and interconnect parasitic to evaluate their impact on resonance, Q, and matching in an RF block.
2. To design a frequency-translation block to analyze key metrics.
3. To design a variable-gain stage to verify gain range and observe noise/linearity trade-offs.
4. To design an oscillator block to verify start-up, tuning range, amplitude, and phase-noise trends.
5. To implement a frequency synthesizer loop to evaluate lock behavior.
6. To design an LO distribution / buffering block to validate isolation / loading effects and their influence on oscillator/synthesizer performance.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Semiconductor Device Characterization (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Semiconductor Device Characterization	4	2	0	2	NIL

Course Objectives:

- Perform DC, pulsed, and RF characterization of semiconductor devices (diodes, MOSFETs, HEMTs, BJTs).
- Extract key parameters (V_{th}, g_m, r_o, R_{ON}, capacitances, f_T / f_{max}) and build compact models for circuit simulation.
- Understand and execute reliability / ageing tests (BTI, HCI, TDDB, EM, self-heating, trapping) and interpret degradation trends.
- Learn measurement automation + data analysis using Python / Matlab and correlation with SPICE / TCAD / compact models.

Course Outcomes:
After completing the course, the students should be able to:

1. Set up semiconductor device measurements using SMU / LCR, Kelvin sensing, calibration.
2. Perform DC and CV characterization of diodes / BJTs / MOSFETs / HEMTs and extract key parameters such as V_{TH}, g_M, r_o, R_{ON}, contact resistance, and capacitances.
3. Carry out pulsed and transient measurements to separate trapping and self-heating effects and extract dynamic R_{ON}, time constants, and thermal RC.
4. Perform RF S-parameter measurements with basic calibration and de-embedding and extract small-signal models and f_T / f_{max} proxies for device evaluation.
5. Execute accelerated reliability stress tests (BTI, HCI, TDDB awareness, self-heating) and interpret ageing / degradation trends with simple lifetime extrapolation.

Unit – I **(15 hours)**
Measurement: Test setups (SMU / curve tracer / LCR), 2-wire vs 4-wire (Kelvin) sensing, guarding and leakage control, ESD precautions, probe station basics, contact resistance and chuck effects, calibrations.

DC / CV characterization: Diode / FET IV curves, threshold extraction, g_M/r_o extraction, subthreshold slope and mobility, R_{ON} and contact resistance, CV measurements, compact model for SPICE.

Unit – II **(15 hours)**
Pulsed / Transient Characterization: pulsed IV and self-heating, trap characterization using stress, recovery transients, dynamic R_{ON} extraction, gate lag / drain lag, charge trapping and time constants (stretched-exponential fitting).

RF Characterization: S-parameters interpretation, calibration basics (SOLT / TRL), de-embedding, small-signal equivalent, f_T / f_{max}. Reliability: accelerated ageing and lifetime extrapolation (Arrhenius), Weibull Plots.

Essential Readings

1. Semiconductor Device Fundamentals by Robert F. Pierret (Addison-Wesley)
2. Semiconductor Devices: Physics and Technology by S. M. Sze and Ming-Kwei Lee (Wiley)
3. CMOS Circuit Design, Layout, and Simulation by R. Jacob Baker (Wiley-IEEE Press)
4. RF Microelectronics by Behzad Razavi (Pearson)

Suggested Readings

1. Microwave Transistor Amplifiers: Analysis and Design by Guillermo Gonzalez (Pearson)
2. Integrated Circuit Failure Analysis: A Guide to Preparation Techniques by Friedrich Beck and Stephen S. Wilson (Wiley)
3. Analysis and Design of Analog Integrated Circuits by Paul R. Gray, Paul J. Hurst, Stephen H. Lewis, and Robert G. Meyer (Wiley)

List of Experiments (Hardware / Software – at least 5) **(60 hours)**

1. To measure diode IV characteristics to extract R_s, Ideality factor (η), and leakage current (and temperature dependence).
2. To measure MOSFET DC characteristics (I_D-V_G and I_D-V_D) to extract V_{TH}, g_M, r_o, and subthreshold slope.
3. To measure R_{ON} versus V_G to estimate ON - Resistance and contact resistance.
4. To perform CV measurements to extract bias dependent capacitances (C_{GS} / C_{GD} / C_{DS}).
5. To set up pulsed IV measurements with chosen pulse width and duty cycle.
6. To compare DC and pulsed measurements to extract dynamic R_{ON} and trapping time constants.
7. To apply gate / drain stress and then measure recovery transients to quantify gate lag / drain lag behavior and trapping signatures.
8. To measure bias-dependent S-parameters of a transistor at multiple bias points.
9. To extract small-signal model parameters (C_{GS}, C_{GD}, R_G, R_S, R_D) and estimate f_T and validate using SSEC Model.
10. To execute stress–measure–recover sequences to extract V_{TH} shift versus time.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Compact Modeling with Verilog-A (DSE – 10 / GE - 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Compact Modeling with Verilog-A	4	2	0	2	Introduction to Electrical and Electronics Engineering, Concepts of CMOS VLSI Design

Course Objectives:

- Develop practical compact models for R / C / L.
- Build compact models for MOSFET and HEMT.
- Implement models in Verilog-A with convergence checks.
- Package models into a mini-PDK with parameter forms and layout generators for devices.

Course Outcomes:
After completing the course, the students should be able to:

1. Develop compact models for resistors, capacitors and inductors and validate them across DC and frequency ranges.
2. Build MOSFET compact models capturing modern architecture trends and verify continuity and charge behavior in simulations.
3. Implement progressive HEMT compact models and validate DC, and small signal trends.
4. Deliver a mini-PDK: Verilog-A models with parameterized layout cells that reflect specifications.

Unit – I **(15 hours)**
Resistor Models: sheet resistance, geometry scaling, contact resistance, temperature coefficient. Capacitor models, frequency. Inductor models, substrate loss, Q-factor, self-resonance, RLC equivalents. Parameter extraction.

Compact Modeling for MOSFET: IV equations, CLM, mobility degradation / velocity saturation, body effect, charge / capacitance partitioning. Parameter extraction.

Unit – II **(15 hours)**
HEMT Modeling: knee behavior, access resistances, nonlinear capacitances, transconductance, breakdown, dispersion. Angelov large signal /ASM / MVSG surface potential / charge based model.

Verilog-A compact models, DC / AC / transient, parameter sweeps, symbols, parameter forms. Layout generation: parameterized layouts for resistor arrays, capacitor shapes, spiral inductors, multi-finger devices.

Essential Readings

1. Operation and Modeling of the MOS Transistor by Yannis Tsividis & Colin McAndrew (Oxford University Press)
2. Device Modeling for Analog and RF CMOS Circuit Design by Trond Ytterdal, Yngvar Berg & Tor A. Fjeldly (Wiley)
3. GaN Transistors for Efficient Power Conversion by Alex Lidow, Johan Strydom, Michael de Rooij & David Reusch (Wiley)
4. Verilog-A Language Reference Manual by Accellera Systems Initiative (Accellera)

Suggested Readings

1. The SPICE Book by Andrei Vladimirescu (Wiley)
2. RF Microelectronics by Behzad Razavi (Pearson)
3. ADS Documentation (PDK / AEL / Model Integration) by Keysight Technologies (Keysight)

<u>List of Experiments</u> (Hardware / Software – at least 5) **(60 hours)**

1. To extract a resistor model to validate geometry scaling and temperature behavior.
2. To build a capacitor compact model and observe CV / impedance-vs-frequency trends.
3. To build an inductor compact model and observe trends.
4. To implement the passive models in Verilog-A to and run DC / AC / transient simulations.
5. To extract a MOSFET compact model parameter set from I_D-V_G / I_D-V_D / g_M / r_o curves.
6. To extend the MOSFET model with simple capacitance model for switching transients.
7. To implement a baseline HEMT compact model to fit DC output / transfer characteristics.
8. To implement a baseline HEMT compact model to fit small-signal trends.
9. To add trapping / dispersion and self-heating to the HEMT model.
10. To create parameterized layout generators for active / passive devices.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

IoT Sensor and Data Integration (DSE – 9 / GE - 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
IoT Sensor and Data Integration	4	3	0	1	Introduction to Embedded Systems for IoT

Course Objectives:

- To understand practical sensor characteristics and select sensors using datasheets for IoT applications.
- To interface analog and digital sensors and build acquisition modules for embedded systems.
- To apply basic signal conditioning and filtering to improve measurement quality.
- To perform calibration, error estimation, and validation for reliable sensor data.

Course Outcomes:
After completing the course, the students should be able to:

1. Select sensors and interfaces for IoT nodes by interpreting range, accuracy, resolution, and bandwidth from datasheets.
2. Interface analog/digital sensors and implement a stable sampling pipeline with timing and timestamping.
3. Apply basic conditioning and filtering techniques to reduce noise and improve data quality.
4. Perform calibration (offset/gain) and prepare simple error/uncertainty notes for measurements.
5. Build a multi-sensor data integration prototype producing clean, validated, and well-structured datasets.

Unit – I **(10 hours)**
Sensor fundamentals for IoT: sensor types, static and dynamic characteristics, response time and bandwidth, analog vs digital sensors, interface choices (analog / ADC, I2C, SPI, UART).

Unit – II **(11 hours)**
Signal Conditioning: scaling and offset, voltage dividers / bridges concept, buffering, RC filtering and anti-aliasing, ADC (reference, sampling time, quantization), sampling strategies (polling vs interrupt vs timer-triggered).

Unit – III **(12 hours)**
Noise and filtering: noise sources, smoothing, moving average / median, simple IIR filter, sampling rate, timestamping and jitter, unit conversion and scaling, data validation (range checks, missing samples), sensor fusion.

Unit – IV **(12 hours)**
Calibration and Validation: one-point / two-point calibration, offset / gain correction, temperature drift observation, repeatability and simple uncertainty notes, storing calibration coefficients, multi-sensor synchronization and data integration.

Essential Readings

1. Sensors and Actuators: Engineering System Instrumentation by Clarence W. de Silva (CRC Press)
2. Internet of Things: A Hands-On Approach by Arshdeep Bahga and Vijay Madisetti (Orient Blackswan Private Limited)
3. Practical Electronics for Inventors by Paul Scherz and Simon Monk (McGraw-Hill Education)
4. Measurement Systems: Application and Design by Ernest O. Doebelin and Dhanesh N. Manik (McGraw-Hill Education)

Suggested Readings

1. Building Wireless Sensor Networks by Robert Faludi (O'Reilly Media)
2. Data Acquisition Handbook by Omega Engineering (Omega Press)
3. Embedded Systems: Real-Time Interfacing to ARM Cortex-M Microcontrollers by Jonathan W. Valvano (Amazon)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. To interface a digital sensor using I2C / SPI / UART and acquire periodic measurement.
2. To interface an analog sensor using ADC and implement fixed-rate sampling using timer-based acquisition.
3. To implement basic hardware signal conditioning using an RC low-pass filter and compare noise levels before and after conditioning.
4. To implement digital filtering methods (moving average and median) and compare smoothing vs response time on sensor data.
5. To measure sampling jitter and timing stability for polling-based sampling versus timer/interrupt-based sampling.
6. To perform two-point calibration for a sensor (offset and gain correction) and store calibration coefficients in non-volatile memory.
7. To study drift and stability by long-duration logging and quantify drift trends and repeatability.
8. To implement a basic sensor fusion using an IMU to estimate tilt / orientation using a complementary filter.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

IoT Reliability Engineering (DSE – 9 / GE - 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	**Tutorial**	**Practical**	
IoT Reliability Engineering	4	3	0	1	Introduction to IoT, Basics of Networks

Course Objectives:

- To introduce reliability engineering concepts in the context of IoT systems.
- To understand failure mechanisms and reliability metrics for IoT devices and networks.
- To study fault-tolerant and resilient IoT architectures.
- To familiarize students with reliability testing, validation and lifecycle management.
- To address safety and security aspects affecting IoT system reliability.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain reliability, availability and maintainability concepts for IoT systems.
2. Analyze failure modes and reliability metrics of IoT architectures.
3. Design fault-tolerant and resilient IoT systems.
4. Apply reliability testing and validation techniques to IoT devices.
5. Evaluate the impact of security and safety on IoT reliability.
6. Develop reliability-aware strategies for large-scale IoT deployments.

Unit – I **(12 hours)**

Concept of reliability, availability, maintainability and safety (RAMS), reliability metrics such as MTBF, MTTR, failure rate and hazard function, bathtub curve, differences between conventional electronic systems and IoT systems, reliability block diagrams applied to IoT architectures.

Unit – II **(12 hours)**

Fault classification, transient, intermittent and permanent faults, redundancy techniques including hardware, software and information redundancy, fault detection, isolation and recovery (FDIR), watchdog timers and checkpointing, graceful degradation and self-healing IoT systems, resilient network topologies.

Unit – III **(11 hours)**

Design for reliability (DfR) and design for testability (DfT) in IoT devices, accelerated life testing, highly accelerated life testing (HALT) and highly accelerated stress screening (HASS), failure analysis techniques including FMEA and FTA, reliability prediction standards.

Unit – IV **(10 hours)**

Interdependence of security and reliability in IoT systems, impact of cyber-attacks on system dependability, secure boot and trusted execution environments, redundancy for secure communications, safety-critical IoT systems, standards and certifications for industrial IoT reliability, case studies from smart grid, healthcare IoT and autonomous systems.

Essential Readings

1. Reliability Engineering by Elsayed A. Elsayed (Wiley)
2. An Introduction to Reliability and Maintainability Engineering by Charles E. Ebeling (McGraw-Hill)
3. Engineering a Safer World by Nancy Leveson (MIT Press)
4. Practical Reliability Engineering by Patrick D. T. O'Connor and Andre Kleyner (Wiley)

Suggested Readings

1. Reliability Engineering and Risk Analysis: A Practical Guide by Mohammad Modarres *et al.* (CRC Press)
2. Maintenance Theory of Reliability by Toshio Nakagawa (Springer)
3. Internet of Things – From Research and Innovation to Market Deployment by Ovidiu Vermesan and Peter Friess (River Publishers)
4. Empowering IoT: Reliability, Network Management, Sensing, and Probabilistic Charging in Wireless Sensor Networks by Muhammad Umar Farooq Qaisar , Weijie Yuan , Paolo Bellavista , Hina Tabassum (Springer)

List of Experiments (Hardware / Software) **(30 hours)**

1. Fault injection and observation in embedded IoT firmware.
2. Implementation of watchdog timers for fault detection.
3. Redundancy implementation for fault tolerance in IoT nodes.
4. Reliability-aware routing simulation in IoT networks.
5. Stress testing of IoT hardware under thermal and voltage variations.
6. Accelerated life testing simulation for IoT components.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

LPWAN IoT Network (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
LPWAN IoT Network	4	3	0	1	Introduction to IoT

Course Objectives:

- To understand LPWAN vs short-range wireless vs cellular IoT based on range, power, and latency.
- To learn LoRa / LoRaWAN through configuration, join, and end-to-end data transfer labs.
- To introduce mesh networking for IoT with multi-hop validation.
- To perform simple link and field testing (RSSI / SNR, range, airtime, payload planning).
- To integrate nodes with a gateway / server → MQTT → application flow.

Course Outcomes:

After completing the course, the students should be able to:

1. Compare IoT wireless options and justify a connectivity choice for a given industrial use-case.
2. Configure LoRa links and operate a LoRaWAN node using a network server.
3. Build a small mesh network and validate multi-hop delivery, latency, and power trade-offs.
4. Plan payload size, duty cycle, and transmission strategy using simple experiments and link metrics.
5. Demonstrate an end-to-end LPWAN / mesh system using a gateway/server bridged to MQTT.

Unit – I **(10 hours)**

Connectivity Requirements: range, data rate, latency, reliability, power, cost; star vs mesh; Wi-Fi / BLE vs LPWAN and cellular IoT (NB-IoT / LTE-M); device identity and provisioning; link metrics (RSSI / SNR).

Unit – II **(12 hours)**

LoRa PhyLayer (chirp spread spectrum), LoRa vs LoRaWAN stack, OTAA / ABP, device classes A / B / C, confirmed / unconfirmed messages, payload sizing, airtime awareness, ADR, gateway and network server.

Unit – III **(12 hours)**

Mesh Fundamentals: roles, commissioning, addressing / routing intuition, latency vs reliability trade-offs, sleep-friendly operation, gateway / border router concept, integrating sensing and command / control.

Unit – IV **(11 hours)**

Gateway /server to MQTT bridge, payload formats, range testing (RSSI / SNR), interference considerations, power budgeting for long-life nodes, multi-node LPWAN / mesh system with end-to-end data delivery.

Essential Readings

1. LoRaWAN 1.0.4 Specification by LoRa Alliance (LoRa Alliance)
2. LoRaWAN System Design Guidelines by LoRa Alliance (LoRa Alliance)
3. Building Wireless Sensor Networks: A Practical Guide to the Zigbee Mesh Networking Protocol by Robert Faludi (O'Reilly Media)
4. MQTT Essentials by HiveMQ (HiveMQ)

Suggested Readings

1. Zigbee Wireless Networking by Drew Gislason (Newnes/Elsevier)
2. Bluetooth Low Energy: The Developer's Handbook by Robin Heydon (Prentice Hall)
3. Designing Connected Products by Claire Rowland *et al.* (O'Reilly Media)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. To establish a LoRa point-to-point link and log RSSI/SNR across different distances and environments.
2. To configure a LoRaWAN node and perform OTAA join and uplink using a network server console
3. To study payload and airtime effects by varying payload size and transmit interval.
4. To conduct range test and study coverage and reliability using packet success rate and link metrics.
5. To bridge LoRaWAN uplinks to an MQTT and verify message format.
6. To form a small mesh network and validate multi-hop delivery.
7. To compare sleep vs always-on operation in a mesh / LPWAN node.
8. To implement a downlink / command-control action (e.g., toggle LED/relay).

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Edge Computing (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Edge Computing	4	3	0	1	Fundamentals of Computer Programming

Course Objectives:

- Introduce the fundamental concepts, architecture, and motivation behind edge computing and its evolution from cloud and fog computing.
- Enable students to understand edge computing architectures, devices, and communication technologies used in real-time and distributed systems.
- Provide knowledge of resource management, performance optimization, and security challenges in edge computing environments.
- Expose learners to practical applications, industry use cases, and emerging trends such as Edge-AI, IoT integration, and 5G/6G-enabled edge systems.

Course Outcomes:

After completing the course, the students should be able to:

1. Explain the concepts, characteristics, and advantages of edge computing and compare it with cloud and fog computing.
2. Describe and analyze edge computing architectures, components, and data flow for various real-time applications.
3. Apply techniques for resource allocation, latency reduction, performance optimization, and security in edge environments.
4. Identify and evaluate edge computing applications in domains such as IoT, smart cities, healthcare, vehicular networks, and Industry 4.0.
5. Analyze current research trends and future challenges in edge computing, including Edge-AI and next-generation wireless networks.

Unit – I **(11 hours)**

Introduction & Fundamentals: Edge Computing - definition, Evolution from Cloud & Fog Computing, Key features: low latency, distributed processing, real-time decisioning, Types of Edge, Edge vs Cloud vs Fog Computing comparison, Use cases and application domains.

Unit – II **(12 hours)**

Architecture & Core Technologies: Edge computing architecture and models, Edge devices, gateways, and micro data centers, Communication protocols & connectivity, Computation offloading and distributed analytics, Multi-Access Edge Computing (MEC) and infrastructure components.

Unit – III **(11 hours)**

Resource Management, Performance & Security: Resource allocation, scheduling, load balancing in edge environments, Measuring performance: latency, throughput, energy efficiency, Data management at the edge, Security challenges, Edge analytics and adaptive systems.

Unit – IV **(11 hours)**
Applications, Current Trends & Future Directions: Industry use cases: smart factories, connected vehicles, real-time AI/ML at edge, Edge AI / Edge intelligence frameworks, Integration with IoT & 5G ecosystems, Emerging paradigms.

Essential Readings

1. Fog and Edge Computing: Principles and Paradigms by Rajkumar Buyya and Satish Narayana Srirama (Wiley)
2. Mobile Edge Computing by Yan Zhang (Springer)
3. Internet of Things: Principles and Paradigms by Rajkumar Buyya and Amir Vahid Dastjerdi (Morgan Kaufmann)

Suggested Readings

1. Edge Computing Fundamentals, Advances and Applications by Anitha Kumari, G. Sudha Sadasivam, D. Dharani & M. Niranjanamurthy (CRC Press)
2. Edge Computing: A Primer by J. Cao, Q. Zhang, and W. Shi (Springer)
3. Edge Computing: From Hype to Reality by Fadi Al-Turjman (Springer)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. Setting Up an Edge Device
   Installation and configuration of an edge device (Raspberry Pi / Jetson Nano / Virtual Edge Node) and required software tools.
2. Data Acquisition at the Edge
   Collect sensor data (temperature, humidity, motion, etc.) using an edge device and store it locally.
3. Edge Data Filtering and Aggregation
   Design and implement data filtering, compression, or aggregation techniques at the edge to reduce network load.
4. Computation Offloading in Edge Computing
   Implement a simple task offloading mechanism between edge device and cloud server and analyze performance.
5. Resource Monitoring and Management at the Edge
   Monitor CPU, memory, and energy consumption of edge devices during application execution.
6. Security Implementation at the Edge
   Implement basic security mechanisms such as authentication, encryption, or secure data transmission for edge applications.
7. Edge Analytics / Edge AI Application
   Deploy a lightweight machine learning model or rule-based analytics on an edge device for real-time decision-making.
8. Mini Project: Real-Time Edge Application
   Design and implement a small edge computing application (smart home, health monitoring, traffic sensing, or industrial monitoring).

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Forensic Image Processing (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Forensic Image Processing	4	3	0	1	Fundamentals of Computer Programming, Fundamentals of Image Processing

Course Objectives:

- Build foundational understanding of images / videos as digital evidence, including forensic acquisition, metadata integrity, hashing.
- Develop practical skills to detect and localize classical image tampering (copy-move, splicing).
- Introduce learning-based forensic methods for manipulation and deepfake detection.
- Provide exposure to forensic biometrics and video forensics.

Course Outcomes:
After completing the course, the students should be able to:

1. Inspect metadata and compression traces to infer source and manipulation likelihood.
2. Detect common tampering (copy-move, splicing) and localize manipulated regions.
3. Evaluate deepfake and synthetic media detectors and interpret failure modes.
4. Apply and evaluate learning-based manipulation/deepfake detection approaches using key metrics.

Unit – I **(12 hours)**
Forensic Foundations: Role of images and videos as digital evidence, forensic image acquisition, image formats: EXIF and metadata integrity, hash-based integrity checks, provenance basics. JPEG compression pipeline, double-compression artifacts, resampling clues, noise patterns.

Unit – II **(11 hours)**
Classical Tamper Detection & Localization: Copy-move detection (block matching / feature matching), splicing cues, illumination inconsistencies, edge artifacts, color filter array (CFA) clues overview, error level analysis (ELA) and when it fails. Producing tamper heatmaps and tuning thresholds responsibly.

Unit – III **(11 hours)**
Learning-Based Forensics: CNN-based manipulation detection, patch-level classifiers, localization networks overview, evaluation metrics (AUC, F1, pixel IoU). Deepfake basics: face swap, reenactment, diffusion-based edits.

Unit – IV **(11 hours)**
Forensic Biometrics: Face, Fingerprint, Iris, Gait; feature extraction and matching; video forensics; frame tampering; camera identification. Watermarking overview (visible/invisible, fragile/robust) and steganalysis, content authenticity initiatives.

Essential Readings

1. Digital Image Processing by Rafael C. Gonzalez and Richard E. Woods (Pearson)
2. Photo Forensics by H. Farid (MIT Press)
3. Digital Image Forensics: There is More to a Picture Than Meets the Eye by Husrev Taha Sencar and Nasir Memon (Springer)

Suggested Readings

1. Deep Learning by Ian Goodfellow, Yoshua Bengio, and Aaron Courville (MIT Press)
2. Computer Vision: Algorithms and Applications by Richard Szeliski (Springer)
3. Practical Cryptography by Niels Ferguson and Bruce Schneier (Wiley)

List of Experiments (Hardware / Software) **(30 hours)**

1. To extract and analyze EXIF / metadata and generate hash checksums to document integrity and provenance indicators for a given image set.
2. To vary JPEG quality and recompress images using FFmpeg/OpenCV to study visible and statistical compression artifacts across quality factors.
3. To detect double JPEG compression signatures to flag probable recompression and compare true/false positives on a small dataset.
4. To implement copy-move detection using feature matching (ORB/SIFT) to localize duplicated regions and generate a tamper heatmap.
5. To train a patch-based tamper classifier to evaluate AUC/F1 and analyze failure cases and bias.
6. To perform robustness testing by applying resize/recompress/blur perturbations to quantify detector sensitivity and produce a robustness table.
7. Watermarking and Steganalysis basics.
8. Video frame extraction and tampering detection.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Computer Graphics (DSE – 9 / GE – 9)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Computer Graphics	4	3	0	1	Concepts of Data Structures

Course Objectives:

- Introduce fundamental concepts of computer graphics.
- Explain key algorithms and techniques for creating graphics.
- Cover generation, manipulation, and display of 2D & 3D objects.
- Build mathematical foundations used in graphics systems.
- Teach rendering techniques used in modern graphics.
- Understand and apply graphical transformations (2D/3D).

Course Outcomes:

After completing the course, the students should be able to:

1. Understand the basic principles and architecture of computer graphics systems.
2. Apply algorithms for drawing and transforming 2D and 3D objects.
3. Implement clipping, viewing, and projection techniques.
4. Understand visible surface detection, illumination, and shading models.
5. Apply computer graphics concepts in practical applications and software tools.

Unit – I **(11 hours)**

Introduction and Graphics Systems: Introduction to computer graphics and applications, Graphics hardware and software, Display devices: raster scan and random scan displays, Input devices and interaction techniques, Graphics primitives and scan conversion, Line drawing algorithms: DDA and Bresenham, Circle and ellipse drawing algorithms.

Unit – II **(12 hours)**

Two-Dimensional Graphics and Transformations: 2D coordinate systems and homogeneous coordinates, 2D transformations: translation, rotation, scaling, reflection, shearing, Composite transformations, Windowing and viewing transformations, Line and polygon clipping algorithms: Cohen–Sutherland, Liang–Barsky, Sutherland–Hodgman.

Unit – III **(11 hours)**

Three-Dimensional Graphics and Viewing: 3D coordinate systems and transformations, 3D transformations and composite transformations, Parallel and perspective projections, Viewing pipeline and 3D viewing transformations, Hidden surface removal techniques: Z-buffer, back-face culling, Introduction to curves and surfaces: Bézier curves and B-splines.

Unit – IV **(11 hours)**

Illumination, Shading, and Advanced Topics: Color models: RGB, CMY, HSV, Illumination models: ambient, diffuse, and specular reflection, Shading techniques: flat, Gouraud, and Phong shading, Texture mapping and anti-aliasing, Introduction to animation and rendering pipeline, Overview of modern graphics: OpenGL concepts, ray tracing basics.

Essential Readings

1. Computer Graphics: Principles and Practice by Foley *et al.* (Pearson)
2. Fundamentals of Computer Graphics by Peter Shirley *et al.* (CRC Press)
3. Interactive Computer Graphics: A Top-Down Approach by Shader-Based OpenGL by Edward Angel and Dave Shreiner (Pearson)

Suggested Readings

1. Computer Graphics with OpenGL by D. Hearn & M. P. Baker (Pearson)
2. Procedural Elements for Computer Graphics by D. F. Rogers (McGraw-Hill)
3. Computer Graphics by Zhigang Xiang (McGraw-Hill)

List of Experiments (Hardware / Software) **(30 hours)**

1. Implementation of DDA and Bresenham line drawing algorithms.
2. Implementation of Midpoint circle and ellipse drawing algorithms.
3. Program to perform 2D transformations (translation, rotation, scaling) on graphical objects.
4. Implementation of composite 2D transformations using homogeneous coordinates.
5. Implementation of line clipping algorithms (Cohen–Sutherland and Liang–Barsky).
6. Implementation of polygon clipping using Sutherland–Hodgman algorithm.
7. Program to perform 3D transformations and projections (parallel and perspective).
8. Implementation of hidden surface removal using Z-buffer algorithm.
9. Implementation of illumination and shading models (Phong/Gouraud shading).
10. Design of a simple OpenGL-based graphics application demonstrating rendering and animation.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Computational Photography and Mobile Imaging (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Computational Photography and Mobile Imaging	4	3	0	1	Fundamentals of Image Processing or Digital Image Processing

Course Objectives:

- Understand the digital camera imaging pipeline and implement key Image Signal Processing stages used in mobile cameras.
- Design practical enhancement pipelines for color, tone, noise, blur and dynamic range.
- Build robust multi-image computational photography features: HDR, panorama, super-resolution.
- Evaluate photo quality using simple objective metrics and / or perceptual checks.

Course Outcomes:
After completing the course, the students should be able to:

1. Acquire and represent images using sampling / quantization, and explain the basic camera / ISP pipeline and color fundamentals.
2. Enhance images using spatial and frequency domain methods for contrast, smoothing, and sharpening with artifact control.
3. Apply restoration methods for noise reduction and deblurring, with practical parameter tuning.
4. Build pipelines for registration, HDR/exposure fusion, and panorama stitching with blending.
5. Analyze compression artifacts and assess quality using PSNR/SSIM and perceptual checks.

Unit – I **(10 hours)**
Digital Image Fundamentals: DIP system, image sensing, acquisition, sampling, quantization, basic radiometry / illumination-reflectance. Color models and transformations, white balance, gamma correction, camera overview (RAW vs JPEG, Bayer pattern).

Unit – II **(12 hours)**
Image Enhancement-Spatial Domain: Point processing, intensity transformations, histogram processing, spatial filtering. Edge-preserving enhancement, local contrast enhancement for mobile photos (CLAHE).

Unit – III **(12 hours)**
Image Enhancement-Frequency Domain & Image Restoration: 2D DFT, frequency-domain filtering, homomorphic filtering for illumination correction. Image degradation / noise models, restoration filters, deblurring, practical denoise - sharpen trade-offs for low-light mobile imaging.

Unit – IV **(11 hours)**
Computational Photography: Image registration, panorama stitching, HDR and exposure fusion, super-resolution via multi-frame fusion, compression in mobile imaging (JPEG/HEIF), image quality assessment.

Essential Readings

1. Digital Image Processing by Rafael C. Gonzalez and Richard E. Woods (Pearson)
2. Computer Vision: Algorithms and Applications by Richard Szeliski (Springer)
3. The Image Processing Handbook by John C. Russ (CRC Press)
4. Handbook of Image and Video Processing by Alan C. Bovik (Academic Press)

Suggested Readings

1. Digital Image Processing by William K. Pratt (Wiley)
2. Learning OpenCV by Gary Bradski and Adrian Kaehler (O'Reilly Media)
3. Multiple View Geometry in Computer Vision by Richard Hartley and Andrew Zisserman (Cambridge University Press)

List of Experiments (Hardware / Software – at least 5) **(30 hours)**

1. To implement gamma correction, log transform, and piecewise linear contrast.
2. To implement histogram equalization.
3. To implement spatial smoothing filters.
4. To implement sharpening (Laplacian, unsharp mask, high-boost) on test images.
5. To implement frequency-domain low-pass and high-pass filtering and to compare with spatial filtering.
6. To simulate motion blur / defocus blur and additive noise and to restore images using a Wiener-style deconvolution baseline.
7. To implement feature-based image alignment and to generate aligned stacks from handheld shots.
8. To build panorama stitching.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)

Image Restoration and Inpainting (DSE – 10 / GE – 10)
(Credit Distribution and Prerequisites of the Course)

Course Title	Credits	Credit Distribution of the Course			Prerequisite of the course (if any)
		Lecture	Tutorial	Practical	
Image Restoration and Inpainting	4	3	0	1	Fundamentals of Image Processing or Digital Image Processing

Course Objectives:

- Develop the ability to model image degradations (noise, blur, compression).
- Implement denoising and deblurring workflow with parameter tuning.
- Build inpainting /object removal workflows using classical method.
- Evaluate and report restoration quality using metrics and perceptual checks.

Course Outcomes:

After completing the course, the students should be able to:

1. Create degradation models (noise / blur / compression) and generate synthetic test cases and datasets for fair evaluation.
2. Implement and compare denoising methods and justify parameter choices using metrics and visual artifact inspection.
3. Apply deblurring / deconvolution (non-blind and blind workflows) and control ringing and amplification artifacts.
4. Perform inpainting / object removal using patch-based techniques and evaluate structure / texture consistency in restored regions.

Unit – I **(11 hours)**

Degradation Models and Evaluation: Image degradation, common noise models, motion / defocus blur intuition, and JPEG characteristics. Controlled experiments using synthetic degradation, train / val / test splits for restoration, and evaluation using PSNR / SSIM.

Unit – II **(11 hours)**

Denoising Methods: Spatial filters, wavelet / transform, non-local means concept. Parameter tuning and over-smoothing control, detail preservation checks, color denoising pitfalls.

Unit – III **(12 hours)**

Deblurring and Deconvolution: Wiener filtering, Richardson–Lucy, regularization, handling ringing artifacts. Blind deconvolution, motion blur estimation heuristics, and robustness to noise and compression.

Unit – IV **(11 hours)**

Inpainting, Super-Resolution and Artifact Removal: Patch-based inpainting, seam and edge consistency. Learning-based inpainting / super-resolution, JPEG artifact reduction, restoration workflow.

Essential Readings

1. Digital Image Processing by Rafael C. Gonzalez and Richard E. Woods (Pearson)
2. Introduction to Inverse Problems in Imaging by M. Bertero & P. Boccacci (CRC Press)
3. Computer Vision: Algorithms and Applications by Richard Szeliski (Springer)

Suggested Readings

1. Digital Image Processing by William K. Pratt (Wiley)
2. Image Processing: The Fundamentals by Maria Petrou and Panagiota Bosdogianni (Wiley)
3. The Image Processing Handbook by John C. Russ (CRC Press)
4. Image Processing and Analysis by T. Chan & J. Shen (SIAM)

List of Experiments (Hardware / Software) **(30 hours)**

1. Simulation of image degradation models.
2. Image restoration using spatial domain filters.
3. Frequency domain restoration and Wiener filtering.
4. Total variation-based image restoration.
5. Image inpainting using exemplar-based methods.
6. Performance evaluation of restoration and inpainting techniques.

(Note: Course instructor may add / delete / update new experiments in addition to the above suggested practical exercises.)