Indian Institute of Space Science and Technology

Department of Space

Govt. of India

Thiruvananthapuram

Curriculum and Syllabus for

VLSI and Microsystems

Department of Avionics

[From Academic Period 2022- 23]

(Approved By Academic Council on 27-4-2022)

Version1/17-05-2022

Program Educational Objectives (PEO):

1. Strengthen analytical skills and the technical knowledge in the area of digital and analog VLSI Design, and Micro Electro Mechanical Systems and applying it to develop Integrated system for various applications.
2. Enable the graduates to pursue research by adopting dynamic academic curriculum; implement innovative learning and research practices to harness curiosity and creativity; inspire and educate the students to analyze and solve complex problems.
3. Enhance the employability of the graduates in Industry/Academia/R&D organizations by inculcating strong theoretical and experimental knowledge in the domain with exposure to real-life and practical applications.
4. Instill deep sense of ethics, social values, professionalism and inter-personal skills among students.

Program Outcomes (PO)

Program Outcomes	Statements
PO1	An ability to independently carry out research/investigation and development work to solve practical problems.
PO2	Ability to write and present a substantial technical report/document.
PO3	Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program.
PO4	Conceptualizing ability to solve simple and complex Design problems in VLSI and Micro Electro systems
PO5	Instill the ability to learn and develop hardware, software modules /IC chips using the state-of-the-art IC/MEMS Design tools.

COURSE STRUCTURE

Semester I

Code	Course Title	L	T	P	C
AVM611	Fundamentals of VLSI devices	3	0	0	3
AVM612	Introduction to Micro Electro Mechanical Systems (MEMS)	3	0	0	3
AVM613	Analog VLSI Circuits	3	0	0	3
AVM614	Digital VLSI Circuits	3	0	0	3
E01	Elective I	3	0	0	3
AVM631	VLSI Design Lab	0	0	3	1
AVM851	Electronic Hardware Design Project	0	0	3	2

Semester II

Code	Course Title	L	T	P	C
AVM621	Micro/Nano Fabrication Technology	3	0	0	3
E02	Elective II	3	0	0	3
E03	Elective III	3	0	0	3
E04	Elective IV	3	0	0	3
AVM641	MEMS Lab	0	0	3	1
AVM642	Microelectronics Lab	0	0	3	1
AVM643	Engineering Design Project	0	0	0	2

Semester III

Code	Course Title	L	T	P	C
AVM853	M. Tech Project-Phase 1	0	0	0	18
	Total	0	0	0	18

Semester IV

Code	Course Title	L	T	P	C
AVM854	M. Tech Project-Phase 2	0	0	0	18
	Total	0	0	0	18

Summary

Semester	Credit
I	18
II	16
III	18
IV	18
Total	**70**

List of Electives:

The electives are divided into three buckets: VLSI bucket, Microelectronics/ Microsystems bucket and Interdisciplinary bucket. The students may choose any combination from any of the buckets. **In addition, any one relevant NPTEL/Swayam course can be taken as an elective.**

VLSI Bucket

Course Code	Course Title
AVM861	Mixed Signal VLSI Design
AVM862	RF Integrated Circuits
AVM863	VLSI Digital Signal Processing
AVM864	Advanced VLSI Design
AVM865	High Speed IO Circuits

Microelectronics/ Microsystems Bucket

Course Code	Course Title
AVM871	Physics of Nano-Electronic Devices
AVM872	Microsystem Integration
AVM873	RF MEMS
AVM874	Sensors and Actuators
AVM875	Thin films: Materials and characterization
AVM876	Power Semiconductor devices
AVM877	Compound Semiconductor devices and Technology
AVM878	Photonic Integrated Circuits

Interdisciplinary Electives

Course Code	Course Title
AV491	Advanced Sensors and Interface Electronics
AVD611	Modern Signal Processing
AVP867	Electronic System Design
MA619	Advanced Mathematics

SEMESTER I

AVM611	Fundamentals of VLSI Devices	(3-0-0) 3 Credits

Review of quantum mechanics, E-K diagrams, effective mass, electrons and holes in semiconductors, band diagram of silicon, carrier concentration, carrier statistics, career transport, junction devices(P-N junction, Metal –semiconductor junctions, solar cells etc.), MOS capacitor as a building block for MOSFETs (Ideal MOS, real/Non-ideal MOS, band diagrams, C-V characteristics, electrostatics of a MOSCAP), MOSFET, I-V characteristics, scaling, short channel and narrow channel effects, high field effects, reliability of transistor.

Textbooks/References:

1. Semiconductor Physics and Devices: Basic Principles, McGraw-Hill, Donald A Neamen, ISBN 0-256-24214-3, 1997.
2. Fundamentals of Modern VLSI Devices, Yuan Taur & Tak H Ning, Cambridge University Press, 1998.
3. Semiconductor Device Fundamentals, Robert F. Pierret, Addison-Wesley, ISBN 020154393-1, 1995.
4. Physics and Technology, E. H. Nicollian and J. R. Brews, MOS, John Wiley, 1982.
5. Complete Guide to Semiconductor Devices, K. K. Ng, McGraw Hill, 1995.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Learning the basics of Quantum mechanics, Crystal structure and Solution of Schrodinger equations for generating Band diagrams. The significance of the band diagram is also discussed to understand the properties of different Semiconductors.
CO2	Strengthen the theoretical concept of the transport properties of Micro and Nano Semiconductor devices.
CO3	Detailed understanding of different semiconductor devices on Micro and Nanoscale followed by analytical modelling.
CO4	Introduction of C-MOS scaling from Micro to Nano transistor and short channel effect.

AVM612	**Introduction to Micro Electro Mechanical Systems (MEMS)**	**(3-0-0) 3 Credits**

Broad-stroke overview – History of Microsystem Technology with overview on commercial products, Sensing & Actuation Principles of Microsystems, Applications-MEMS Materials and Fabrication Technology, Microelectronic technologies for MEMS, Micromachining Technology: Surface and Bulk Micromachining, Design and modelling of MEMS/Microsystem: Mechanics of MEMS/Microsystems-Elasticity-Stress/strain analysis of beams, membranes etc., thin film stress-Dynamics of Microsystems, MEMS Transduction Mechanisms: Optical, piezoelectric, piezoresistive, FET based transduction etc. MEMS sensors and applications and case studies

Textbooks/References:

1. Microsystem Design, S. D. Senturia, 2005.
2. Foundations of MEMS, Chang Liu, Pearson Publication.
3. Analysis and Design Principles of MEMS Devices, Minhang Bao.
4. Fundamentals of Microfabrication Science of Miniaturization, Marc Madau, CRC Press.
5. Micro and Smart Systems Technology and Modeling, G. K. Ananthasuresh, K. J. Vinoy, S. Gopalakrishnan, K. N. Bhat, V. K. Aatre, 2012.
6. Peer-reviewed international journals such as IEEE/ASME Journal of MEMS, IOP Journal of Micromechanics and Microengineering, IOP Journal of Nanotechnology, Elsevier Sensors and Actuators etc. and conference proceedings such as IEEE MEMS, IEEE Nanotechnology, Transducers etc.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Gaining basic understanding of Microsystem Technology, sensing and actuation.
CO2	Strengthen the theoretical concept of MEMS materials, fabrication techniques, micromachining.
CO3	Ability to design and model MEMS systems.
CO4	Understanding various transducing mechanisms.

AVM613 Analog VLSI circuits (3-0-0) 3 Credits

Basic MOS device. Overview of non-ideal behaviour of deep sub-micron MOS transistors. Analysis and design of current mirrors and current sources. Analysis and design of single stage amplifiers, differential amplifiers: Small signal analysis, frequency response, noise, linearity. Analysis and design of OTA circuits – differential pair, cascodes, folded-cascodes, two-stage OTAs. Stability, frequency compensation, MRR, PSRR. Feedback. Fully differential op-amps, CMFB. Bandgap references. Output stages. Switched-capacitor circuits, comparators.

Textbooks/References:

1. Design of Analog CMOS Integrated Circuits, Behzad Razavi, McGraw Hill.
2. Analog Design Essentials, Willy M. C. Sansen, Springer.
3. Analysis and Design of Analog Integrated Circuits by Gray, Hurst, Lewis and Meyer, Wiley.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Learning basics of MOS devices, MOS transistors, and design current sources and mirrors.
CO2	Design single stage and differential amplifiers and understand their frequency response and noise.
CO3	Analyze the characteristics of combinational circuits using different logic styles and different parameters and methods to obtain delay.
CO4	Design OTA circuits – differential pair, cascodes and folded-cascodes.
CO5	Learning the concept of feedback and using them to design OPAPMs, bandgap references.

AVM614	**Digital VLSI Circuits**	**(3-0-0) 3 Credits**

Overview of CMOS device fundamentals (DC Characteristics, AC Characteristics, Processing overview). CMOS inverters, Static and Dynamic characteristics, Dynamic behavior, transition time, Propagation Delay, Power Consumption. MOS Circuit Layout & Simulation, Stick diagrams, Layout design rules, MOS device layout, Transistor layout, Inverter layout, circuits layout. Combinational logic, Static MOS, Complementary MOS, Ratioed logic, Pass Transistor logic, Complex logic circuits, DSL, DCVSL, Transmission gate logic. Dynamic MOS design, Dynamic logic families and their performance. MOS Memory design, Design of ROM, SRAM and DRAM cells. and sequential CMOS logic, Modelling of interconnect wires. Optimization of designs with respect to cost, reliability, performance, and power dissipation. Sequential circuits: timing considerations, and clocking approaches. Design of large system blocks, including arithmetic, interconnect, memories, and programmable logic arrays.

Introduction to Hardware Description Language. Layout Generation and Verification: Behavioral, Structural, Physical level.

Textbooks/References:

1. Digital Integrated Circuits, Anantha P. Chandrakasan and Jan M. Rabaey, PHI Learning
2. CMOS VLSI Design, David Harris & Neil Weste, Pearson Education, India.
3. Analysis and Design of Digital Integrated Circuits, David Hodges, Horace Jackson, Resve Saleh, McGraw-Hill Series in Electrical and Computer Engineering.
4. CMOS Digital Integrated Circuits, Sung Mo Kang, Yusuf Leblebici, McGraw-Hill Higher Education.
5. Verilog -HDL A guide to Digital Design and Synthesis, Pearson, 2003.

Course Outcomes (COs):

Course outcomes	**Statements**
CO1	Learning basics of different logic families, electrical characteristics of digital logic gate, CMOS implementation of logic gate and fundamentals of CMOS device characteristics of inverter, design the layout of CMOS logic gates using MOSIS rules.
CO2	Design and analyze the characteristics of combinational circuits using different logic styles and different parameters and methods to obtain Delay.
CO3	Model interconnects and to design and analyze sequential circuits using different logic styles and optimizations in terms of performance parameter, and learning to design digital circuits using hardware description language.
CO4	Designing and analyzing large system blocks such as ALU, memories

E01	Elective	(3-0-0) 3 Credits

Refer the Elective List

AVM631	VLSI Design Lab	(0-0-3) 1 Credits

Introduction of software: Analog design flow, digital design flow

Digital:

Design of a complex digital circuit (e.g. an ALU or a multiplier) using high-level hardware description languages, logic simulation and timing simulation. Extraction of critical paths and circuit simulation of critical path sub-circuits. Circuit partitioning and realisation using FPGAs or PALs.

Analog:

Basic MOS device characterization. Current mirrors – design and simulation to meet given specifications. Design and simulation of single-stage amplifiers. OTA design – at least two topologies meeting different sets of specifications. Analog layout and extraction. Design of an analog subsystem meeting a given requirement.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Learn basics of analog and digital design flows.
CO2	Design complex digital circuits, and understand logic simulation and timing simulation.
CO3	Extract crucial paths and critical paths, and understanding circuit partitioning.
CO4	Understand basic MOS characterization and design current mirrors.
CO5	Design and simulate amplifiers having different specifications.

AVM851 Electronic Hardware Design Project (0-0-3) 2 Credits

Introduction: Electronic Hardware Design – Requirement and Challenges, Overview of Design tools (LTSPICE, Microcontroller usage and coding, PCB Design softwares)

Stage 1: Design, Simulation, Analysis and Implementation of a typical (analog + digital) electronic module. Realization and testing of a bread-boarded model, followed by PCB schematic design. Fabrication of PCB using etching machine. Preferably Two students in a batch

Stage 2: Execution of an electronic design case study (preferably individual projects) and demonstrate its real-time working and applications.

Stage 3: Summarize the design project (methodology, analysis, results and inferences) in the form of a detailed report.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Understanding the design, simulation and analysis of analog and digitizing electronic systems
CO2	Implementing the electronic hardware designs with the help of proper selection of analog components, microcontroller platform and related coding, PCB designing and fabrication, and soldering
CO3	Ability to evaluate the hardware design and comprehend the state-of the art test/measurement equipment
CO4	Gain the ability to comprehend and execute an electronic hardware project and summarize the methodology and results in form of a research report.

SEMESTER II

AVM621	Micro/Nano Fabrication Technology	(3-0-0) 3 Credits

Classical scaling in CMOS, Moore's law, clean room concept, material properties, crystal structure, lattice, growth of single crystal Si, cleaning and etching, thermal oxidation, dopant diffusion in silicon, deposition & growth (PVD, CVD, ALD, epitaxy, MBE, ALCVD etc.), ion-implantation, lithography (Photolithography, EUV lithography, X-ray lithography, e-beam lithography etc.), etch and cleaning, CMOS process integration, back end of line processes (Copper damascene process, Metal interconnects; Multi-level metallization schemes), advanced technologies (SOI MOSFETs, Strained Si, Silicon-Germanium MOS, High K, metal gate electrodes and work function engineering, double gate MOSFETs, FinFETs, Gate All Around (GAA) etc.), emerging research devices and architectures

Textbooks/References:

1. Silicon VLSI Technology, James Plummer, M. Deal and P. Griffin, Prentice Hall Electronics.
2. The Science and Engineering of Microelectronics, Stephen Campbell, Oxford University Press, 1996.
3. VLSI Technology, S.M. Sze (Ed), 2nd Edition, McGraw Hill, 1988.
4. ULSI Technology, C.Y. Chang and S.M.Sze (Ed), McGraw Hill Companies Inc, 1996.
5. Peer-reviewed international journals such as IEEE Electronic Device Letters, Transactions on Electron Devices, Journal of Microelectronics, etc. and conference proceedings such as International Electron Device Meeting (IEDM), IRPS, etc.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Gain the ability to understand basics of scaling, Moore's law, understand the importance of crystal planes, crystal orientation, various semiconductor lattices.
CO2	Develop proficiency in the growth of single crystal silicon, various oxidation techniques and diffusion of impurities, learning various deposition and growth techniques for semiconductor layers.
CO3	Develop proficiency in various semiconductor fabrication techniques such as photolithography techniques, semiconductor etching techniques (dry and wet). Understanding various interconnect schemes.
CO4	Ability to evaluate the importance of high-k and low-k dielectric materials.

E02	**Elective II**	**(3-0-0) 3 Credits**

Refer the Elective List

E03	**Elective III**	**(3-0-0) 3 Credits**

Refer the Elective List

E04	**Elective IV**	**(3-0-0) 3 Credits**

Refer the Elective List

AVM641 **MEMS Lab** **(0-0-3) 1 Credits**

Module 1: Design and simulation

This module focuses on design and simulation aspects of sensors, actuators and sensor systems. The laboratory course provides an overview of numerical and analytical modelling and design of microsystems using leading software in the field such as Coventor, MEMS+ or COMSOL Multiphysics for MEMS

Module 2: Fabrication and characterization of MEMS devices

1. Familiarization of unit processes and Fabrication of MEMS structures such as Micro cantilever beam/suspended membrane etc.
2. Characterization (Electrical, Mechanical and Electromechanical) of MEMS structures

Reference:

List same as that for the theory courses on MEMS and Thin films

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Develop proficiency in using advanced TCAD softwares such as coventor, MEMS+ or COMSOL multiphysics.
CO2	Understanding various unit processes for the fabrication of MEMS structures.
CO3	Apply design methodologies for fabricating and characterizing MEMS devices.
CO4	Summarize the work, results and inferences as a concise report

AVM642 **Microelectronics Lab** **(0-0-3) 1 Credits**

Module 1: Microelectronics Device and Process Simulation Syllabus. This module focuses on the simulation of fabrication processes and the microelectronics devices such as short channel MOSFET etc. using TCAD tools for Micro and nanoelectronic devices. The process simulation enables one to experiment with the device fabrication flow. The device simulation involves simulating the electrical characteristics of a process simulated/fabricated device.

Module 2: Microfabrication and characterization 1. Familiarization of Microfabrication environment in clean room 2. Familiarization of different unit processes, Fabrication of MOS Capacitor 3. Electrical characterization: High frequency capacitance-voltage measurement (HFCV) and High frequency capacitance-voltage measurement (LFCV), I-V and reliability measurements, parameter extraction of MOS devices, M-S and P-N junction devices

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Gain hands-on experience with the fabrication, characterization, and analysis of microelectronic devices such as MOSFETs, BJTs, diodes, and capacitors, understanding the physical principles and operation of these devices through practical experiments.
CO2	Develop skills in various microfabrication techniques, including photolithography, etching, doping, oxidation, and thin-film deposition.
CO3	Perform I-V, C-V, and other characterization techniques to evaluate device performance and extract key parameters.
CO4	Summarize the work, results and inferences as a concise report

AVM643 Engineering Design Project (0-0-0) 2 Credits

Design and develop initial design concepts and architectures that are in the area of VLSI and Microsystems using VLSI/CAD design tools based on a set of practical specifications.

Analysis of VLSI circuits and microsystems and efficacy determination with the help of simulation tools.

The layout and test plans/mask layout for hardware verification/fabrication of the simulated system/device

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Develop proficiency in using advanced VLSI design tools and softwares such as Cadence, Synopsys, Mentor Graphics, or TCAD softwares for device design and process optimization for microelectronic devices.
CO2	Apply design methodologies for creating complex VLSI circuits and microsystems, including analog, digital, and mixed-signal designs.
CO3	Encourage innovative thinking by developing unique design solutions to address specific engineering challenges.
CO4	Summarize the work, results and inferences as a concise report

Semester III

AVM854	M. Tech Project-Phase 1	(0 0 0) 18 Credits

Semester IV

AVM854	M. Tech Project-Phase 2	(0 0 0) 18 Credits

VLSI Bucket Elective List:

AVM861	Mixed Signal VLSI Design	(3-0-0) 3 Credits

Basics of data conversion systems. Sampling theory. Sample and hold circuits. Linearity, noise in mixed signal systems. Comparator design. Preamplifier design. Offset – source, analysis, offset cancellation. ADC topologies – comparative study and analysis. Analysis and design of multiple DAC architectures. Deriving OpAmp specifications from system level requirements. Non-idealities in ADCs and DACs and compensation techniques. Impact of layout parasitics on the performance of ADCs and DACs. Introduction to high-speed wireline communication circuits. Transmitter architectures, and circuits, equalization techniques. Receiver architecture, overview of clock and data recovery circuits, equalization.

Textbooks/References:

1. CMOS Mixed-Signal Circuit Design, R. Jacob Baker, Wiley.
2. CMOS – Circuit Design, Layout and Simulation, R. Jacob Baker, Wiley.
3. Design of Analog CMOS Integrated Circuits, Behzad Razavi, McGraw Hill.
4. Analog Design Essentials, Willy M. C. Sansen, Springer.

AVM862 RF Integrated Circuits (3-0-0) 3 Credits

On-chip RF passive components, resonant circuits, matching circuits. Noise – source, modelling, noise figure, noise temperature, noise figure of cascaded systems. Linearity – HD, IMD, IP2, IP3. ACLR, AACLR. Basics of wireless communication. LNA design, Input matching for power, input matching for noise. Advanced LNA circuits. Mixer topologies – active and passive. Receiver architectures. Voltage controlled oscillator topologies – theory and design, phase noise. Phase locked loops (PLL) – theory, design of individual elements and the complete system. Power amplifier classes and topologies – theory and design. Transmitter and receiver architectures.

Textbooks/References:

1. RF Microelectronics, Behzad Razavi, Pearson.
2. The Design of CMOS Radio-Frequency Integrated Circuits, Thomas H. Lee, Cambridge.

AVM863 VLSI Digital Signal Processing (3-0-0) 3 Credits

Introduction to Digital Signal Processing; Need of VLSI DSP algorithms. Main DSP Blocks and typical DSP Algorithms. Number Representation: Fixed point Representation Floating point Representation; Binary Adders; Binary Multiplier; Binary Dividers; Floating point Arithmetic Implementation: CORDIC architectures; Multiply Accumulator unit; Computation of Special functions using MAC cells. Redundant arithmetic, redundant number representations, carry free radix 2 addition and subtraction. Hybrid radix 4 addition. Radix 2 hybrid redundant multiplication architectures, data format conversion. Redundant to non-redundant converter. Numerical strength reduction.

Bit level arithmetic structures- parallel multipliers, interleaved floor plan and bit plan based digital filters. Bit serial multipliers. Bit serial filter design and implementation. Canonic signed digit arithmetic, Distributed arithmetic.

Synchronous pipelining and clocking styles, clock skew and clock distribution in bit level pipelined VLSI designs.

Parallel FIR filters. Pipelining of FIR filters. Parallel processing. Pipelining and parallel processing for low power FIR filters. Pipeline interleaving in digital filters.

Pipelining and parallel processing for IIR filters. Low power IIR filter design using pipelining and parallel processing, Pipelined adaptive digital filters.

Systolic Array Architectures and fast convolution algorithms.

Round off noise and its computation. State variable description of digital filters, Scaling using slow-down, retiming and pipelining.

Textbooks/References:

1. VLSI Digital Signal Processing Systems - Design and Implementation, Keshab K. Parhi, Wiely, 2010.
2. High-Performance VLSI Signal Processing, – Innovative Architectures and Algorithms, Systems Design and Applications, K. J. Ray Liu, IEEE Press, 1998.
3. System Design with System, C Thorsten Grotker, et al, Kluwer Academic Publishers, 2002.
4. Digital Signal Processing with Field Programmable Gate Arrays, U Meyer Baese Springer 2009.
5. FPGA-based Implementation of Signal Processing Systems, Roger Woods, 2008.
6. Design of Analog-Digital VLSI Circuits for Telecommunication and Signal Processing, Jose E. France, Yannis Tsividis, Prentice Hall, 1994.

AVM864 Advanced VLSI Design (3-0-0) 3 Credits

Power-speed-noise trade-off. Ultra-lower power VLSI design. Leakage power vs dynamic power. Minimum energy point concept. Low voltage analog, mixed-signal design. VLSI design for IoT applications. Low voltage memories.

Designing for high speed/performance. Dynamic voltage and frequency scaling. Selected topics on clock skew, clock routing, power routing. Selected topics on layout techniques in mixed-signal circuits – guard rings, etc. Role of calibration in modern ICs.

Textbooks/References:

Journal and conference papers.

AVM865 High Speed IO Circuits (3-0-0) 3 Credits

Introduction to high speed links. Review of PCB trace behavior at high frequencies. Concepts of cross-talk, dispersion, inter-symbol interference (ISI). Transceiver schemes. Design of transmitter, output impedance matching, multiplexing techniques, clocking, signaling techniques. Pre-distortion and equalization. Link budgets. Design of receivers – continuous time linear equalizers, slicers, DFE techniques, clocking, critical paths, IIR/FIR implementations. PLLs, clock and data recovery circuits and schemes.

Textbooks/References:

1. CMOS Nano electronics Analog and RF VLSI Circuits, S. Palermo, McGraw-Hill, 2011. Journal papers, conference papers.

Microelectronics/ Microsystems Bucket Elective List:

AVM871	Physics of Nano-Electronic Devices	(3-0-0) 3 Credits

This Nano-Electronics course provides an introduction to more advanced topics, including the Non-Equilibrium Green's Function (NEGF) method widely used to analyse quantum transport in nanoscale devices. The course will explore topics within Nano-Electronics, taking a more in depth look at quantum transport, gaining greater insight into the application of the Schrodinger Equation, and learning the basics of spintronics which is now a days recent trends in next-generation Nano-Electronics. The quantum of conductance, Potential profile, Coulomb blockade Electrical resistance Basic of Quantum Mechanics, The quantum of conductance, Potential profile, Coulomb blockade Electrical resistance Hamiltonian Operator, Born-Oppenheimer approximation, Hydrogen Atom, Method of Finite Difference, Solution of Schrodinger Equation of 1D, 2D and 3D materials (spherical Coordinate). Introduction of Energy level Diagram, E-K diagram, Nano-transistor, Electron flow, Quantum Conductance, Potential Profile, Molecular, Ballistic and Diffusive Transport, Landauer Model for Transistor, Landauer-Buttiker Formalism, Coulomb blockade, Hall effect, Scattering theory of Transport. Modified Hamiltonian and Self-Consistent Field method, Relation to the Multielectron picture, Bonding, Coherent and non-coherent Transport, NEGF equation, Spin matrics, Spi-Orbit Introduction, Spin Density with Current and Torque.

Case study of different nanostructure (Quantum wells, wires, dots, and nanotubes). Computational approach to calculate band diagram and other electrical properties.

Textbooks/References:

Journals and patents

AVM872	Microsystem Integration	(3-0-0) 3 Credits

MEMS Foundry processes, CMOS-MEMS Integration: Design and technology, Bonding & Packaging of MEMS, MEMS reliability, non-silicon MEMS, Interface electronics for sense and drive in microsystems, MEMS and circuit noise sources, Noise and Offset Cancellation Technique, testing and calibration approaches in integrated microsystems.

MEMS Sensors and Actuators: Case Studies (Mechanical, Inertial, bio/chemical, Microfluidics, RF Applications.); Future Directions and developments (Integrated Nano-Electro-Mechanical Systems (NEMS), NEMS oscillators and sensors)

Textbooks/References:

1. Microsystem Design, S. D. Senturia, 2005.
2. Advanced Micro and Nano systems, Baltes, Brand, Fedder, Hierold, Kowenk, Tabata, Vol. 1, Enabling Technology for MEMS and Nano devices, Wiley-VCH, 2004.

3. Analysis and Design of Analog Integrated Circuits Gray, Hurst, Lewis, & Meyer, 4th edition, Wiley, 2004.
4. Fundamentals of Microfabrication Science of Miniaturization, Marc Madau, CRC Press.
5. Micro and Smart Systems Technology and Modeling , G. K. Ananthasuresh, K. J. Vinoy, S. Gopala Krishnan, K. N. Bhat , V. K. Aatre, 2012.
6. Peer reviewed international journals such as IEEE/ASME Journal of MEMS, IOP Journal of Micromechanics and Micro engineering, IOP Journal of Nanotechnology, Elsevier Sensors and Actuators etc. and conference proceedings such as IEEE MEMS, IEEE Nanotechnology, Transducers etc.

AVM873	**RF MEMS**	**(3-0-0) 3 Credits**

Introduction to RF MEMS, Electrical and mechanical modelling of MEMS devices, MEMS Switches: Introduction to MEMS switches; Capacitive shunt and series switches: Physical description, circuit model and electromagnetic modelling; Techniques of MEMS switch fabrication and packaging; Design of MEMS switches. RF Filters and Phase Shifters: Modeling of mechanical filters, micro machined filters, surface acoustic wave filters, micro machined filters for millimeter wave frequencies; Various types of MEMS phase shifters; Ferroelectric phase shifters. MEMS Varactor, MEMS Resonators micro machined waveguide components; Micro machined antennas: Micromachining techniques to improve antenna performance, reconfigurable antennas. Integration and Packaging for RF MEMS: Role of MEMS packages, types of MEMS packages, module packaging, packaging materials and reliability issues.

Textbooks/References:

1. RF MEMS and their Applications, Varadan, V.K., Vinoy, K.J. and Jose, K.J., John Wiley & Sons. 2002.
2. MEMS: Theory Design and Technology, Rebeiz, G.M., John Wiley & Sons. 1999.
3. RF MEMS Circuit Design for Wireless Communications, De Los Santos, H.J, Artech House, 1999.

AVM874	**Sensors and Actuators**	**(3-0-0) 3 Credits**

Introduction and historical background, Microsensors : Sensors and characteristics, Integrated Smart sensors, Sensor Principles/classification-Physical sensors (Thermal sensors, Electrical Sensors, tactile sensors, accelerometers, gyroscopes , Proximity sensors, Angular displacement sensors, Rotational measurement sensors, pressure sensors, Flow sensors, MEMS microphones etc.), Chemical and Biological sensors (chemical sensors, molecule-based biosensors, cell-based biosensors), transduction methods(Optical, Electrostatic, Electromagnetic, Capacitive, Piezoelectric, piezo resistive etc.), Micro actuators : Electromagnetic and Thermal micro actuation, Mechanical design of micro actuators, Microactuator examples,-micro valves, micropumps, micrometers- Microactuator systems : e.g. Ink-Jet printer heads, Micro-mirror TV

Projector. Introduction to interfacing methods: bridge circuits, Programmable gain instrumentation amplifiers, A/D and D/A converters, microcontrollers

Applications and case studies: Micro sensors and actuators in environmental sensing, RF/Electronics devices, Optical/Photonic devices, micro sensors for space applications, MEMS sensors in navigation systems, radiation sensors, Medical devices, Bio-MEMS

Textbooks/References:

1. Micromechanical Transducers: Pressure sensors, accelerometers, and gyroscopes, M.-H. Bao, Elsevier, New York, 2000
2. Microsensors, Richard S. Muller, Roger T. Howe, Stephen D. Senturia, RosemaryL. Smith, and Richard M. White, IEEE Press, IEEE Number PC 0257-6, ISBN 0-87942- 254-9, New York, 1991.
3. Micromechanics and MEMS: Classic and Seminal Papers to 1990, William Trimmer, IEEE Press, IEEE Number PC4390, ISBN 0-7803-1085-3, New York.
4. Mechanical Measurements, Beckwith T. G., Margoni R. D., Lienhard J. H. New York: Addison-Wesley Pub. Co, 1995
5. Micro and Smart Systems, G. K. Ananthasuresh, K. J. Vinoy, S. Gopalakrishnan, K.N. Bhat, and V. K. Aatre, Wiley-India, 2010.

AVM875	**Thin films: Materials and characterization**	**(3-0-0) 3 Credits**

Material Science: introduction, structure, defects, bonds and bands, thermodynamics of material, kinetics, nucleation.

Thin film nucleation: Atomic view of substrate surfaces, thermodynamic aspects of Nucleation, Kinetic processes in Nucleation and growth.

Epitaxy: Lattice mismatch and defects in epitaxial film, epitaxy of compound semiconductors, High and low temp. methods of deposition.

Structural and chemical characterization of films and surfaces. XRD, TEM, AFM, SEM,

Interdiffusion: compound formation, phase transformation in thin film, metal-semiconductor reaction, mass transport in thin film.

Mechanical properties of thin films: Mechanical testing and strength of thin films, analysis of internal stress

Textbooks/References:

1. Micro- and Opto- Electronic Materials and Structures: Ephrahim Suhir, Y.C Lee, C. P Wong, Springer Publishers
2. Thin Film Phenomena: Kasturi L. Chopra, McGraw Hill, New York
3. Thin Film Device Applications: Kasturi L. Chopra, Indrajeet Kaur, Springer, USA
4. The Materials Science of Thin Films: Milton Ohring, Academic Press
5. Handbook of Thin Films Deposition Processes and Techniques: Principles, Methods, Equipment, and Applications: Klaus K. Schuegraf, Noyes Publications
6. Thin Film Physics: O. S. Heavens, Methuen publishers

AVM876 **Power Semiconductor devices** **(3-0-0) 3 Credits**

Introduction to Power Semiconductor devices, Device Basic Structure and Characteristics, High current effects in diodes, Breakdown considerations for various devices, Schottky rectifiers. - P-i-N rectifiers Power BJTs, Parasitics in Power Transistors, Power MOSFETs, Thyristors, Power Insulated Gate Transistors, Heat transfer in power devices, device packaging

Textbooks/References:

1. Fundamentals of Power Semiconductor Devices, Baliga,G.J., Springer.
2. Physics of Semiconductor Devices, S.M. Sze, 2nd ed., Wiley, 1981.

AVM877 **Compound Semiconductor devices and Technology** **(3-0-0) 3 Credits**

Fundamentals of Semiconductors: Carrier concentration of semiconductor, Transport Equations, P-N Junction Diode, Schottky Junction Diode and MOSFET. Fundamentals of Compound Semiconductors: Introduction of Compound Semiconductors, Properties of Compound Semiconductors, Synthesis of Compound Semiconductors.

High-Frequency Devices: Essential Condition of High-frequency device and compound semiconductor, Fundamentals of MESFET, Concept of Pinch off and threshold voltage, I-V characteristics of MESFET, trans conductance, equivalent circuit and figure of merit of MESFET, Short channel effect, Velocity saturation and velocity overshoot effect of GaAs based MESFET, Evolution of HEMT from MESFET structure, HEMT and triangular potential well, I-V and gate control, Fabrication of MESFET and HEMT structures. Optical Devices: Fundamentals of compound semiconductor-based optical devices, Optical density of States, fundamentals and formation of Heterostructures devices.

Fundamentals of LED, essential band structures of LED. Fundamentals of semiconductor LASER with detail theory.

Technology: Synthesis of Compound semiconductors, Fabrication of MESFET and HEMT structures, Fabrication of LED and LASER structures.

Textbooks/References:

1. Semiconductor Optoelectronic Devices, Bhattacharya Pallab, Pearson.
2. Semiconductor Devices, M.K.Achuthan and K N Bhat, The McGraw Hill.
3. Fundamentals of Semiconductor Fabrication, Gary S. May, Simon M. Sze, Wiley.

AVM878 Photonic Integrated Circuits (3-0-0) 3 Credits

Electronic integrated circuits, Scaling of electronic devices, Electrical interconnects, issues with electrical interconnection, Optical interconnects-advantages-similarities with electrical interconnects. Integration-Photonic Integrated Circuits (PIC)-brief history of PIC-Features-Materials for PIC platform-Si, Silica, SOI, III-V, LiNbO3. Basic theory of Planar and channel waveguide-effective index method-guided modes. Types of waveguides-Optical losses in waveguides-(side wall scattering, bending, losses due to metal layer)-waveguide fabrication (LiNbO3 and III-V based).

Passive devices for photonic integrated circuits -waveguides-splitters-directional coupler-waveguide bends-coupled and uncoupled waveguides-application to directional coupler-gratings, DBR mirrors, Photonic crystals Switches and modulators for photonic integrated circuits -controlling guided waves-electro-optic effect, electro absorption effect, Quantum Confined Stark Effect (QCSE), -acousto-optic effect, – thermo-optic effect, -magneto-optic effect, plasma-dispersion effect, non-linear optic effect.

Phase modulators, intensity modulators, microring resonators, fabrication techniques, materials (Si, glass, polymer, III-V), multi-layer processing, all-optical switching, filters, transverse modulators, optical switches, self-electro optic devices (SEED)

Light sources and detectors for photonic integrated circuits: Edge emitting lasers, vertical cavity surface emitting lasers (VCSEL), advantages of VCSEL for interconnects, basic design. plasmonic lasers, single photon lasers, Resonant cavity enhanced photo detectors, pin photodetector, MSM photo detector

Silicon photonics: advantages and disadvantages of Silicon for photonics-Fabrication of Si waveguide devices-SIMOX-BESOI-Wafer splitting-SOI-submicron waveguides, Silicon light sources (LED, LASER), porous Silicon, Si nanocrystals, Raman effect based Si devices SiGe devices, QCSE effect in SiGe, SiGe modulator.

PIC configuration: Examples of III-V based PIC, Si based PIC, III-V on Si based PIC, OPTO-VLSI, chip-chip, board-board interconnect architecture, bi-directional interconnects, selected configurations from recent literature, free space interconnection.

Textbooks/References:

1. Optical integrated circuits, Nishihara, Hiroshi, Masamitsu Haruna, and Toshiaki Suhara. McGraw Hill Professional, 1989
2. Diode Lasers and Photonic Integrated Circuits, Larry A. Coldren and Scott W. Corzine. Wiley.

Course Outcomes (COs):

Course outcomes	Statements
CO1	Familiarization of the fundamental differences between electrical and optical interconnection, limitations of electrical interconnects, advantages of optical interconnects, To develop proficiency in understanding light propagation in optical interconnects [fibers, waveguides], loss mechanisms and modal analysis in optical waveguides
CO2	Designing various passive optical fiber components used in optical interconnects. And understanding the construction, operating principle and their features.
CO3	Learning the construction, operating principle, types and features of various optoelectronic devices [Sources, modulators/switches, amplifiers, detectors] that are used in optical interconnects.
CO4	Familiarization of design principles used in various photonic integrated circuits configurations [III-V based, Si based, III-V on Si based]

Interdisciplinary Electives:

AV491 Advanced Sensors and Interface Electronics (3-0-0) 3 Credits

Introduction and Background of state-of-art sensing and measurement techniques. Contactless potentiometer (resistance-capacitance scheme) – Methodology, Interface Circuits, Overview of Flight Instrumentation. Analog Electronic Blocks, CMRR Analysis (Non-ideal OpAmps) of an Instrumentation Amplifier, Linearization circuits for single- element Wheatstone bridges (application to strain gauge), Direct Digital Converter for Strain gauges, Signal conditioning for Remote-connected sensor elements. Inductive sensors and electronic circuits, Eddy-current based sensors, Synchros and Resolvers, Magnetic shielding techniques. State-of-art Magnetic Sensors – Principle, Characteristics and Applications – Induction Magnetometer, Flux gate Magnetometer, Hall Effect Sensor, Magnetoresistance Sensors, GMR Sensors – Multi-layer and Spin Valve, Wiegand Effect, SQUID.

Case Study-1: GMR Based Angular Position Sensor, Sensing Arrangement, Linearization Electronics – Methodology, Circuit Design and Analysis.

Case study-2: Brake Wear Monitoring, Reluctance-Hall Effect Angle Transducer–Sensing Arrangement, Front-end Electronics. Overview of Basic Capacitive sensors. Various design considerations; guarding, stray fields, offset and stray capacitance, Ratio metric measurement – advantages and circuit implementations. RMS, Peak, Average Value Electronic Schemes for Capacitive Sensors, Synchronous Phase Detection – multiplier and switching type.

Case study-3: Liquid level detection – Concentric Cylindrical Plates, Plates on container walls – Dielectric and Conductive Liquids - Analysis. Case study-4: Capacitive Angle Transducers and Front-end electronics. Piezoelectric sensors, Seismic transducers. Introduction to MEMS, Piezoelectric, Electrodynamic and MEMS Capacitive Accelerometers, Principles of Ultrasonic sensors - Equivalent circuit and transfer function of a piezoelectric transmitter, crystal oscillator. NDT using ultrasonic and eddy-current. Optical and Fibre Optic Sensors MEMS Pressure sensors, Vacuum-pressure estimation and important flow measurement (volume and mass flow rate) schemes, Flapper-nozzle systems. Sensing Schemes for Attitude, Position measurement and navigation, Instrumentation Systems for Occupancy Detection – Ultrasound, Inductive and Capacitive schemes. Non-contact current and voltage measurement, Newhuman vital-sign sensing techniques.

Textbooks/References:

1. Sensors and Signal Conditioning, Ramón Pallás-Areny, John G. Webster, 2nd Edition, Wiley, 2003.
2. Measurement systems: Application and Design, Doebelin, E.O., 5th ed., McGraw hill, 2003.
3. The Measurement, Instrumentation and Sensors Handbook, J. G. Webster, Vol 1 and 2, CRC Press, 1999.
4. Capacitive Sensors – Design and Applications, L. K. Baxter, IEEE Press Series on Electronic Technology, NJ, 1997.
5. Handbook of Modern Sensors – Physics, Designs and Applications, Jacob Fraden, Springer, 4th Edition, 2010.
6. Principle of Measurement Systems, John P. Bentley, Pearson Education; 3rd Edition, 2006
7. Fundamentals of Industrial Instrumentation, A. Barua, Wiley, 2013.

AVD611	**Modern Signal Processing**	**(3-0-0) 3 Credits**

Analysis of LTI system: Phase and Magnitude response of the system, Minimum phase, maximum phase, Allpass. Multirate Signal Processing: Interpolation, Decimation, sampling rate conversion, Filter bank design, Polyphase structures. Time-frequency representation; frequency scale and resolution; uncertainty principle, short-time Fourier transform. Multi-resolution concept and analysis, Wavelet transform (CWT, DWT). Optimum Linear Filters: Innovations Representation of a Stationary Random Process, Forward and Backward linear prediction, Solution of the Normal Equations. Power Spectral Estimation: Estimation of Spectra from Finite Duration Observations of a signal, the Periodogram, Bartlett, Welch and Blackman, Tukey methods, Comparison of performance of Non-Parametric Power Spectrum Estimation Methods. Parametric Methods: Auto-Correlation and Model Parameters, AR (Auto-Regressive), Moving Average (MA), and ARMA Spectrum Estimation. Frequency Estimation-Eigen Decomposition of autocorrelation matrix, Piscaranko’s Harmonic

Decomposition Methods, MUSIC Method. Adaptive Filter Theory: LMS, NLMS and RLS, Linear Prediction. DSP Processor architecture- DSP Number representation for signals, Study of Fixed point and floating-point DSP processor and its architectures.

Textbooks/References:

1. Digital Signal Processing, Mitra, S. K., 3 rd Edition, McGraw Hill 2008.
2. Discrete-time signal processing, Oppenheim, Alan V - Pearson Education India.
3. Multirate Systems and Filter Banks, P.P. Vaidyanathan, Prentice-Hall, 1993.
4. Statistical digital signal processing and modeling, Monson H.Hayes, Jhon Wiley & Sons.
5. Wavelet Basics, Y. T. Chan, Kluwer Publishers, Boston, 1993.
6. A Friendly Guide to Wavelets, Gerald Kaiser, Birkhauser, New York, 1992.
7. Digital signal processing: principles algorithms and applications, Proakis, John G. - PHI.
8. Adaptive filter theory, Haykin, Simon S, Pearson Education India.

Pre-requisites:
1. Undergraduate Signals and Systems
2. Undergraduate Digital Signal Processing

AVP867	**Electronic System Design**	**(3-0-0) 3 Credits**

Module 1: Role of Interface Electronics, Analog Electronic Blocks, OpAmp – internal structure, Open- loop gain, Input R, Output R, DC noise sources and their drifts, CMRR, PSRR, Bandwidth and stability, Slew rate, Noise – general introduction, OpAmp Circuits and Analysis - Difference and Instrumentation Amplifiers (3-opamp and 2-opamp), Effect of cable capacitance and wire-resistance on CMRR, IA with guards, Biomedical application, Current-mode IA (Howland), Current-input IA, filters, Filters with underdamped response, state-variable filters, All-pass filters, Current Sources (floating and grounded loads), PGA, V-to-f converters, Negative Resistance Generator, Gyrator, GIC and applications, Quadrature oscillator, Introduction to switched capacitor circuits and applications, OTA and applications.

Module 2: Frequency and Time Measurement, Sample Hold Circuits, ADCs and their properties, Different ADC Architectures – Single Slope, Dual Slope (with emphasis on DMM), SAR, Flash, Sigma- Delta. Voltage references and regulators,

Module 3: Basic electronic design concepts - potential divider, component packages, burden/loading effects, Error budgeting – Zener drift, resistance drift, voltage offsets and bias current errors, Transistor as amplifier – Basic circuit, loading effects; transistor as a switch – Darlington pairs, drivers, high-side drives, transistor latch.

Module 4: Analog controllers – temperature controller, error amplifier, integral controller, PI controller, PID controller, system TC Vs sensing TC.

Module 5: Transistor (linear) voltage regulator – over current protection, fold-back protection, voltage regulator with bypass, heat-sink design, regulator design with LDOs, current sources – high side loads, grounded loads with reference w.r.t. Ground, current sources with 3 pin regulator ICs, 4-20mA current transmitters, loop powered circuits.

Module 6: Special topics: PLL, isolation amplifiers, gate drivers, oscilloscope probes (gain selection circuits), techniques for power management.

Mini Projects for Internal Assessment (Selected topics)

1. 250.000 mA precision current source design.
2. 4-20mA current transmitter.
3. Implementation of OpAmp-based active filters.
4. Capacitance multipliers or gyrators
5. One quadrant multiplier with PWM IC
6. Sensor linearization circuit
7. High fidelity headphone amplifier
8. Power grid voltage–angle detector with analog PLL

Textbooks/References:

1. Sensors and Signal Conditioning, Ramón Pallás-Areny, John G. Webster, 2nd Edition, Wiley, 2003.
2. Design with Operational Amplifiers and Analog Integrated Circuits, Sergio Franco, 3rd Edition, McGraw hill, 2002.
3. Analog Signal Processing, Ramón Pallás-Areny, John G. Webster, 1st Edition, Wiley, 2011.
4. Operational Amplifiers, George Clayton, Steve Winder, 5th Edition, Elsevier Newnes, 2003.
5. Opamps and Linear Integrated Circuits, Ramakant A. Gayakwad, PHI India, 4th Edition.
6. Capacitive Sensors – Design and Applications, IEEE Press Series on Electronic Technology, L. K. Baxter, NJ 1997.
7. Principle of Measurement Systems, John P. Bentley, Pearson Education; 3rd Edition, 2006.
8. The art of electronics Horowitz, P., & Hill, W. (3rd ed.). Cambridge University Press, 2015.

MA619	Advanced Mathematics	(3-1-0) 4 Credits

Vectors: Representation and Dot products, Norms, Matrices: The Four Fundamental Spaces of a Matrix, The Matrix as a Linear Operator, The Geometry associated with matrix operations, Inverses and Generalized Inverses, Matrix factorization/Decompositions, rank of a matrix, Matrix Norms. Vector spaces: Column and row spaces, Null Space, Solving Ax=0 and Ax=b, Independence, basis, dimension, linear transformations, Orthogonality: Orthogonal vectors and subspaces, projection and least squares, Gram-Schmidt orthogonalization, Determinants: Determinant formula, cofactors, inverses and volume, Eigenvalues and Eigenvectors: characteristic polynomial, Eigen spaces, Diagonalization, Hermitian and Unitary matrices, Spectral theorem, Change of basis, Positive definite matrices and singular value decomposition, Linear transformations, Quadratic forms.

Review of Probability: Basic set theory and set algebra, basic axioms of probability, Conditional Probability, Random variables - PDF/PMF/CDF - Properties, Bayes theorem/Law of total probability, random vectors - marginal/joint/conditional density functions, transformation of Random Variables, characteristic/moment generating functions, Random sums of Random variables, Law of Large numbers (strong and Weak), Limit theorems - convergence types, Inequalities - Chebyshev/Markov/Chernoff bounds.

Random processes: classification of random processes, wide sense stationary processes, autocorrelation function, and power spectral density and their properties. Examples of random process models - Gaussian/Markov Random process, Random processes through LTI systems.

Textbooks/References:

1. Introduction to linear algebra - Gilbert Strang, SIAM, 2016.
2. Introduction to probability - Bertsekas and Tsitsiklis, Athena, 2008.
3. Probability and Random processes for Electrical Engineers, Leon Garcia Addison Wesley, 2nd edition, 1994.
4. Probability and Random Processes, Geoffrey Grimmett, David Stirzaker, 3rd Edition, Oxford University Press, 2001.
5. Probability and Stochastic Process, Roy D Yates, David J Goodman, 2nd edition Wiley, 2010.