The University Of Sheffield.

Electronic & Electrical Engineering.

EEE348   ELECTRONICS AND DEVICES

Credits: 20

Course Description including Aims

This course aims to describe the generic circuit elements, analogue and digital, which are typically used within IC circuits (their associated properties and the underlying semiconductor theory). Additionally, this course aims to bring the student to a level of understanding of VLSI design, such that they can:

1. Understand the alternatives available to and constraints that act upon a VLSI designer.
2. Understand the underlying technologies, trends, and critical issues that affect and will affect VLSI design.
3. Design and analyse analogue and digital circuits (and understand the limitations)
4. Review semiconductor band structure, doping, conduction, junctions
5. Introduce the various electronic material systems (Si, Ge, III-V, GaN) and outline their electronic properties and principal applications
6. Introduce different semiconductor alloys and heterojunctions used in electronic devices.
7. Demonstrate performance and functional improvements possible using alloys and heterojunctions.
8. Review Solar Cell developments encompassing single and multijunction, as well as thin film solar cells.
9. Introduce optical detector technologies and applications for different wavelength ranges
10. Explore heterostructure optoelectronic devices such as Lasers, LEDs
11. Introduce high speed electronic devices for microwave applications

Outline Syllabus

VLSI
Introduction: Technology development: historical perspective, trends, and future problems and issues.
Economics and Design Styles: Economics of chip production. Economics of chip design.
Implementation options: Full custom; cell based, Gate Arrays, FPGAs and Programmable Logic Devices. **Synchronous Design**: Methodology. Clocks and clocking. **Logic design**: CMOS technology and characteristics. Noise margins. Gate design/sizing. Switching speed. **Analogue circuit structures**: Circuit operating characteristics of BJTs and MOSFETs; single transistor circuit elements; two transistor circuit elements; differential amplifiers; current mirrors and output stages.
Analogue VLSI design: CMOS operational amplifier.

Semiconductors
Fundamental Properties: Band structure, doping, carrier concentrations, generation and recombination processes, transport properties, p-n homojunctions, heterojunctions. **Semiconductor Materials:** review of whole family of semiconductors, specific electronic properties, chemical properties, main applications. **Solar Cells:** materials, device structure types, efficiencies, projections. **Optoelectronic devices:** LEDs, Lasers, detectors, figures of merit, applications and wavelengths. **High Speed Devices:** IMPATT, tunnel diodes, Gunn diodes, negative differential resistance, comparison of performance.

Time Allocation

48 lectures plus 24 hours of additional support material.

Recommended Previous Courses

Some previous knowledge of MOSFET operation is assumed, EEE118 Electronic Devices and Circuits would be appropriate. A familiarity with digital circuit design is essential, EEE117 Digital System Engineering provides a suitable background.

Assessment

5-out-of 8 question, 3 Hour Examination

Recommended Books

K Eshragian	*Principles of CMOS VLSI Design A Systems Perspective*	Addison Wesley
	Technology Roadmap for Semiconductors 2001	http://public.itrs.net
Uyemura J P	*Introduction to VLSI Circuits and Systems*	Wiley
Rabaey J	*Digital Integrated Circuits - A Design Perspective*	Prentice Hall
Geiger R L, Allen P E & Strader N R	*VLSI Design Techniques for Analog and Digital Circuits.*	McGraw Hill
Gray P R, Hurst P J, Lewis S H, Meyer R J	*Analysis and Design of Analogue Integrated Circuits*	Wiley
Sedra, A and Smith, K	*Microelectronic circuits*	OUP
Simon Sze and Ming-Kwei Lee	*Semiconductor Devices Physics and Technology*	Wiley
S.M.Sze and Kwok K. Ng	*Physics of Semiconductor Devices*	Wiley
Streetman and Banerjee	*Solid State Electronic Devices*	Prentice Hall
David Pulfrey	*Understanding Modern Transistors and Diodes*	Cambridge

Objectives

By the end of this unit successful students will be able to:

1. Demonstrate an understanding of the costs, options, technological difficulties, behaviour of, and benefits of VLSI for particular applications;
2. Calculate the costs (to a first order) of a VLSI design;
3. Use the appropriate terminology associated with VLSI;
4. Outline the VLSI design process and the methodologies used in system implementation;
5. Design simple logic gates based on an understanding of the required logic and the behaviour of the technology. Students should also be able to estimate the performance of these gates (power, speed, area).
6. Design simple analogue IC structures to achieve particular goals.
7. Identify those parts of a circuit that play a major role in limiting the frequency response and write down and use the high frequency equivalent circuit of a circuit to calculate high frequency behaviour.
8. Understand design issues relate to VLSI operational amplifiers and analyze analogue circuits for CMOS operational amplifiers.
9. Demonstrate an understanding of how semiconductors are used to make functional electronic and optoelectronic devices in common use today
10. Articulate the differences between the various semiconductors and why they are used in specific

applications
11. Discuss the role of heterojunctions in optoelectronic devices, the range of materials available and the wavelengths covered
12. Demonstrate awareness of the various solar cell materials and designs to achieve cost effectiveness and efficiency
13. Identify and justify detector technologies according to applications
14. Demonstrate understanding of how LEDs and Lasers operate.
15. Demonstrate an understanding of speed-related issues of microwave devices
16. Show an awareness of current and potential future technologies for microwave devices

Detailed Syllabus

1. Introduction and historical background to VLSI.
2. Trends in VLSI and future problems/issues - the SIA Roadmap.
3. Design routes - Gate Array, Standard Cell, Full Custom, FPGA and PLD.
4-5. Economic constraints and costs
6. Outline of design process and the role of simulation.
7. Introduction to CMOS technology.
8-9. Performance of simple gates - CMOS inverter, Transmission Gate. A simple RC model.
10. Gate design and sizing.
11. Switching speed of more complex gates.
12. Synchronous design. Clocks and clocking. Metastability.
13. Review of the operating characteristics and small signal models of BJTs and MOSFETs. The Miller transformation.
14. Single transistor circuits including common source, common gate and source follower and their input/output impedance, applications and frequency behaviour. Source degeneration and the Miller Effect.
15. Cascode configurations and their useful characteristics.
16. Differential pairs, mode of operation, linear behaviour, CMRR, derivation of common mode and differential mode ½ circuits.
17. Current mirrors, mode of operation, issues due to early effect, use as an active load and a current source.
18. The 2-stage differential amplifier: design, analysis and VLSI issues.
19. CMOS operational amplifier : a review and VLSI design issues.
20. CMOS operational amplifier : a review and VLSI design issues, continued.
21-23. Crystals, band structure, transport, semiconductor materials and their properties,
24-25. Carrier generation and recombination processes
26-27. Solar Cells operating principles, materials and technologies
28-30. Photodetector technologies for high speed applications, APDs and Infrared detection
31-32. Discussion and revision of previous topics
32-33. LEDs operating principles, use of quantum wells, blue and white LEDs
34-37. Lasers operating principles, DFB, quantum wells, quantum dots
38-40. Microwave devices, negative differential resistance, IMPATT diodes
41-42. Tunnel diodes and Gunn Diodes
43-44. Revision

UK-SPEC - IET Learning Outcomes
Outcome Code   Supporting Statement

SM1p/SM1m   Elements of circuit theory and semiconductor device behaviour are considered (Underlying materials, bandstructure and control of carriers in electronic devices). This is assessed by examination.

SM2p/SM2m   Various algebraic manipulations and differential calculus employed along with aspects of Boolean algebra. This will be assessed, where appropriate, within relevant questions.

SM3p/SM3m   The course considers VLSI across a range of levels from system down to device and naturally draws from semiconductors, circuit theory and (to a smaller extent) system design (e.g. feedback). Aspects of this knowledge and understanding will be assessed in the examination.

EA1p   Part of the course looks at the analysis, evaluation and design of electronic devices and digital and analogue building blocks, allowing the students to undertake (some times simplified) analyses of behaviour and performance (e.g. small signal modelling, frequency response, Bode plots). The ability to understand and apply these principles are assessed in the examination.

EA1m   Students will be expected to understand and apply the circuit analysis of both analogue and digital circuits (intended for VLSI circuits). Students should be able to deploy these skills either in the analysis of existing circuits or the design of new circuits. This aspect will be assessed by relevant examination questions.

EA2p   Simple mathematical modelling is used to describe the behaviour of logic circuits e.g. speed, area, cost. Analogue circuit analysis – frequency response. This ability to characterise performance is assessed in the examination. Additionally, the analytical modelling of semiconductor devices is considered.

EA2m   Students will be expected to understand and apply the circuit analysis of both analogue and digital circuits (intended for VLSI circuits). Students should be able to deploy these skills either in the analysis of existing circuits or the design of new circuits. This aspect will be assessed by relevant examination questions.

EA4p/EA4m   Appreciation of systems application of devices

EA5m   Although an introductory course, students are provided with sufficient grounding to allow application of the principles covered to new and unfamiliar cases – this will particularly be the case in the analysis of analogue circuits.

D1p/D1m   The course considers approaches to designing systems based on cost, complexity, volume, performance, and domain to identify the critical choices that must be made. Students are expected to be able identify critical issues and make reasoned arguments for a choice of technology in relevant questions in the examination.

D5p/D5m   Trends and process limitations/issues/challenges are considered as part of the underlying economic issues associated with VLSI design. Test and the economics of test/design for test are also considered. Students might be expected to address these issues and make reasoned arguments in answering examination questions.

D5p/D5m   Cost/efficiency evaluation of solar cells and photodetectors

D7m   Design methodologies, design flows, and processes and how these impact on design. Students are expected to be able to describe the need for and applicability of methodologies in answering relevant examination questions.

ET2p/ET2m   The economics of VLSI design and time to market are considered. Students are expected to understand the critical role that time to market plays and how such things as reuse/SoC, etc. can be used to mitigate cost escalation. Students will be expected to address the costing of design in relevant examination questions.

EP2p / EP2m   Students will understand the basics of IC fabrication and associated costs, issues, trends,

and limitations. Students will also be expected to make use of circuit simulation tools such as Spice and to be aware of the limitations of circuit analysis in such cases.

EP4p/EP4m   Students will be made aware of relevant papers and the SIA roadmap

EP5p/EP5m   Students will know the critical role of design reuse and IP blocks and their impact on SoC design and design costs.

EP9m   Students are made aware of the pivotal role of the roadmap in predicting future capability, Additionally, students will know what the future challenges and likely limits of VLSI are.