Course guide
2301219 - ISCIRD - Integrated Sensors and Circuits for Radiation Detectors and Imagers

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Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 1004 - UB - (ENG)Universitat de Barcelona.

Degree: MASTER'S DEGREE IN SEMICONDUCTOR ENGINEERING AND MICROELECTRONIC DESIGN (Syllabus 2024). (Optional subject).

Academic year: 2025 **ECTS Credits:** 4.0 **Languages:** English

LECTURER

Coordinating lecturer: DAVID GASCON FORA

Others:

PRIOR SKILLS

Recommended background:
1. The course is based on basic concepts of microelectronics and semiconductor physics. Specifically, it assumes knowledge on MOS transistor behavior and modeling, circuit implementation in microelectronic technologies, amplification, and analog circuit analysis, as well as circuit simulation and layout edition in Cadence Virtuoso environment or similar tools.
2. Students are advised to have completed the following subjects of the Master: “Microelectronic design”, “Analog IC design” and “Integrated Circuits Physical design”.

LEARNING RESULTS

Knowledges:
KT01. Identify semiconductor devices, technological processes, the most appropriate microelectronic design tools, and relationships between these elements in order to integrate a given product or system into microelectronic technologies.
KT02. Describe the current state of scientific research and microelectronic industrial technology worldwide and their economic, social and environmental impact.
KT03. Describe the physical principles underlying current semiconductor devices in relation to their application, as well as their emerging trends, modelling and characterisation techniques.
KT04. Identify and describe the different manufacturing and characterisation processes in microelectronics and their applicability according to the functional and cost requirements of the final integrated product.
KT05. Describe the main methods and tools used to design integrated circuits and systems in accordance with the required functional specifications and cost of the final integrated product.
KT06. Identify and describe the main verification and test strategies for integrated circuits and systems according to their application.

Skills:
ST01. Design integrated devices, circuits and systems for new products according to their applications, taking into account sustainability and energy efficiency requirements.
ST02. Apply the manufacturing techniques and processes and design, simulation and characterisation tools of semiconductor engineering and microelectronic design to provide a solution to a specific integrated system proposal.

Competences:
CT01. Design new devices and integrated systems that require the use of manufacturing techniques specific to microelectronic technologies or the use of microelectronic design tools.
CT02. Apply sustainability criteria to projects based on integrated microelectronic products.
CT03. Apply the processes of semiconductor engineering and microelectronic design to fields in diverse areas of science or engineering where integrated systems are required.

TEACHING METHODOLOGY

- Lectures
- Individual work (distance)
- Lab design work (analysis and simulation)
- Final examination

LEARNING OBJECTIVES OF THE SUBJECT

This course is an introduction to solid state radiation detection in light sensing (imagers) and radiation detection (X-ray, gamma-ray, charged particles). The applications of imagers and radiation detectors are ubiquitous, including consumer electronics (smartphones, digital cameras, etc.), medical imaging (X-ray machines, PET/SPECT scanners, etc.), automotive industry (advanced driver assistance systems (ADAS) and parking assistance systems), security and surveillance, industrial imaging, aerospace and defense, quantum communications, and scientific instruments. The course introduces both semiconductor sensors and design techniques for integrated readout circuits. The course starts with an introduction to the interaction of particles with matter and photon detection fundamentals. In terms of microelectronics design, the most important techniques are related to low noise front-end electronics, active pixel sensor design, specific digitization methods, and imager readout architectures. Additionally, by leveraging the concepts of radiation interaction with matter, the course introduces radiation-tolerant design, which is critical in aerospace applications and nuclear facilities, and is also increasingly important in the telecommunications and computer industry due to technology scaling. The course counts with industrial participation.

The specific objectives of the course are:
1. Explain the fundamentals of the interaction of radiation with matter and signal formation.
2. Understand different solid-state radiation and photon detection technologies, including active pixel sensors (APS), hybrid pixel detectors, CMOS imagers, Single Photon Avalanche Diode (SPAD) sensors, etc.
3. Know detector analog and digital pulse processing readout circuits applied to radiation detectors (with an emphasis on microelectronics and ASIC design).
4. Understand the fundamentals of imagers and pixelated detectors: pixel architectures in APS, peripherals (addressing, readout circuits, ADCs)
5. Gain insight into packaging and advanced interconnect technologies (monolithic sensors, hybrid sensors, 3D integration, etc.) for integrated detectors.
6. Understand basic concepts related to radiation-tolerant design.

STUDY LOAD

Type	Hours	Percentage
Self study	70,0	70.00
Hours small group	12,0	12.00
Hours large group	18,0	18.00

Total learning time: 100 h

CONTENTS

1. Introduction to solid state detectors.

Description:
Interaction of particles with Matter. Fundamentals of photodetection. Ionizing and non-ionizing radiation detection. Applications (scientific, industrial, automotive, IoT and medical).

Full-or-part-time: 7h
Theory classes: 2h
Self study : 5h

2. Custom integrated readout electronics

Description:
Architectures: pulse processing vs integrating. Low noise techniques. Main front end analog building blocks: preamplifiers, shapers, discriminators, baseline restoration and peak detection. ADC and TDC implementation for detectors and imagers. Integrated electronics for fast photosensors.

Full-or-part-time: 21h
Theory classes: 6h
Self study : 15h

3. Integrated Image Sensors

Description:
CMOS and CIS sensors and imagers. Sensing elements (diodes, pinned diodes, buried diodes, SPADs). Readout architectures: addressing, column parallel ADCs and high-speed serialisers. Sensor characterization and figures of merit.

Full-or-part-time: 13h
Theory classes: 4h
Self study : 9h

4. Integrated radiation detectors.

Description:
Hybrid pixel detectors. Monolithic pixel detectors. Other semiconductor detectors. Packaging and interconnection for integrated detectors.

Full-or-part-time: 13h
Theory classes: 4h
Self study : 9h

5. Radiation Tolerant Design

Description:
Radiation effects on electronics. Design techniques for cumulated dose damage. Design and architectural techniques for single event (SEEs) tolerance. Procedures and standards for qualification of the operation of integrated circuits in radiation environments.

Full-or-part-time: 6h
Theory classes: 2h
Self study : 4h

6. Practical design laboratory projects.

Description:
The student will apply the concepts and skills learned in the course to the design of two circuits implemented in a CMOS microelectronic technology, using the Cadence Virtuoso IC design environment:
1. Design of a front-end system following a top-down approach. The work will start by the behavioral description of a signal processing channel including preamplifier, shaping and digitization. After that, transistor level design of a charge amplifier considering low noise techniques will be performed.
2. Design of an active pixel sensor and readout circuit of an imager. Based on the model of the pixel photosensor different readout options will be explored for pinned.

Full-or-part-time: 40h
Theory classes: 12h
Self study : 28h

GRADING SYSTEM

- Final examination: 30 %
- Labs: 50 %
- Exercises to do at home or in class: 20 %

BIBLIOGRAPHY

Basic:
- Rivetti, Angelo. CMOS : front-end electronics for radiation sensors. Boca Raton: CRC Press, 2015. ISBN 9781138827387.
- Knoll, Glenn F. Radiation detection and measurement. 4th ed. Hoboken, New Jersey: Wiley, cop. 2010. ISBN 9780470131480.
- Ohta, J. Smart CMOS image sensors and applications. 2nd ed. Boca Raton: CRC Press, 2020. ISBN 9781032652368.
- Turchetta, R. Analog electronics for radiation detection. Boca Raton: CRC Press, 2016. ISBN 9781138586024.
- Fossum, E. R.; Hondongwa, D. B.. "A Review of the Pinned Photodiode for CCD and CMOS Image Sensors". EEE Journal of the Electron Devices Society [on line]. 2 (3): 33–43, 2014 [Consultation: 10/05/2024]. Available on: https://ieeexplore-ieee-org.recursos.biblioteca.upc.edu/document/6742594.

Complementary:
- Spieler, Helmuth. Semiconductor Detector Systems. 1. Oxford: Oxford University Press, 2005. ISBN 9780198527848.
- Kolanoski, H.; Wermes, N. Particle detectors: fundamentals and applications. Oxford: Oxford University Press, 2020. ISBN 9780198858362.

RESOURCES

Other resources:
Course slides, exercises, and tutorials available through the Atenea virtual campus.