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

Last modified: 20/03/2024

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: 2024 **ECTS Credits:** 4.0 **Languages:** English

LECTURER

Coordinating lecturer: Gascon Fora, David

Others: Gómez Fernández, Sergio
Casanova Mohr, Raimon
Serra Graells, Francesc

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”.

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

title english

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

title english

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: 40 %
- Labs: 40 %
- 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.