University of Southern California
Ming Hsieh Department of Electrical and Computer Engineering

EE 599: Integrated Circuits in Implantable Medical Devices

4 units | M-W, 4:00 – 5:50 pm | Location GFS 213 | Fall 2019

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Office Hours: TBD

Course Description

Implantable medical devices (IMDs) have enabled novel applications in medicine covering fundamental research, diagnostics, and therapeutics. The electronics in these devices significantly impact the overall performance and functionality of the system. In this course, we cover the design of integrated circuits for IMDs and explore current trends in this area. Some of the topics include implantable biosensors, retinal prostheses, and neural interfaces. The course includes a final design project using state-of-the-art semiconductor technology and industry-standard CAD tools. This project will be related to the transistor-level design, analysis, and simulation of an integrated circuit used in these devices such as neural amplifiers or neural stimulators.

Learning Objectives

This course is a graduate-level course covering the design and analysis of integrated circuits for IMDs and provides fundamental insights and design principles for understanding and developing such systems. Specifically, students will learn: (i) basics of implantable electronic systems used in medical applications and the trade-offs associated with these devices; (ii) basics of electrochemical methods such as electrode-solution interface, amperometric detection, and potentiometric detection, and how they apply to the design of IMDs; (iii) neural interfaces for recording and stimulation of neurons, and implantable biosensors for health monitoring; (iv) circuit and system techniques for the design of such systems; (v) clinical examples of IMDs including neural prosthetics such as retinal, cochlear, and motor prosthesis, and health monitoring devices such as continuous glucose monitoring; (vi) survey of current trends in IMDs.

Prerequisite: EE 479

Recommended Preparation: analog integrated circuit design, basic VLSI design, knowledge of hardware-description languages such as Verilog.

Course Notes

The course will primarily use instructor-written handouts and recent papers in the field of implantable medical devices. Presentation slides (PPT) will be used in some of the lectures and made available to the students. All of these materials will be posted in Blackboard.

Technological Proficiency and Hardware/Software Required

Remote connection to university central server is required to use Cadence tools. Matlab/Python is required for some homeworks.

Required Readings and Supplementary Materials

Mandatory reading: Available in Blackboard

1. Instructor-written handouts
2. Research papers as needed

Additional reading material: Available in USC Libraries

1. Gray, P. (2009). *Analysis and design of analog integrated circuits* (5th ed.). New York ;: Wiley.
2. Razavi, B. (2017). *Design of analog CMOS integrated circuits* (Second edition.). New York, NY: McGraw-Hill Education.
3. Allen, P., & Holberg, D. (2012). *CMOS analog circuit design* (3rd ed.). New York ;: Oxford University Press, USA.
4. Johns, D., & Martin, K. (1997). *Analog integrated circuit design.* New York: John Wiley & Sons.
5. Weste, N., Harris, D., & Weste, N. (2005). *CMOS VLSI design : a circuits and systems perspective* (3rd ed.). Boston: Pearson/Addison-Wesley.
6. Hodges, D., Jackson, H., & Saleh, R. (2004). *Analysis and design of digital integrated circuits : in deep submicron technology* (3rd ed.). Boston: McGraw-Hill Higher Education.
7. Rabaey, J., Chandrakasan, A., & Nikolić, B. (2003). *Digital integrated circuits : a design perspective* (2nd ed.). Upper Saddle River, N.J.: Pearson Education.
8. Sarpeshkar, R. (2010). *Ultra low power bioelectronics : fundamentals, biomedical applications, and bio-inspired systems* . Cambridge, UK ;: Cambridge University Press.
9. Bard, A., & Faulkner, L. (2001). *Electrochemical methods : fundamentals and applications* (2nd ed.). New York: John Wiley.
10. Kandel, E., Schwartz, J., Jessell, T., Siegelbaum, S., Hudspeth, A., & Mack, S. (2013). *Principles of neural science* (Fifth edition.). New York, N.Y.: McGraw-Hill Education LLC.

Description and Assessment of Assignments

1. **Homeworks:** Weekly homeworks will be assigned to cover the topics discussed during that same week and will be due the following week. They will include analysis and design problems, and simulation exercises using Cadence.

2. **Project:** The course includes a comprehensive design project that will consist of a transistor-level design, analysis, and simulation of a complete integrated circuit such as a high-performance neural amplifier or neural stimulator in Cadence environment using

state-of-the-art semiconductor technology. The project will have two parts. The first one will consist of the design of a building block of the system and has to be completed individually. The second part will consist on the design and integration of the full-system and has to be completed in groups of two students, where each one will be required to indicate their individual contribution. Students will present an individual report at the end of the first part, and a final group report and oral presentation at the end of the second part. The project grading will be based on design creativity, achieved specifications, completeness of the written reports including comparison between analysis and simulation results, and the quality of the oral presentation including answering to the questions posed by the instructor and other classmates. The approximate timeline for the project is as follows:

a. Monday of week 6: Project Announcement
b. Wednesday of week 11: Due date for individual report
c. Monday of week 15: Due date for electronic submission of the project schematic
d. Wednesday of week 15: Oral presentations, and due date for submission of final report

3. **Midterm and Final**

Grading Breakdown

Assignment	Points	% of Grade
Homeworks		30
Midterm		20
Final		20
Project		30
TOTAL		100

Assignment Submission Policy

- **Homeworks:** All homeworks are due on Mondays at the beginning of the lecture. Solutions will be posted on Blackboard on the same day.
- **Late Policy:** Late homework will not be accepted except for institution-established emergency reasons. Credit for such late homework is with the discretion of the instructor.
- **Make-up Exams:** Make-up exams will not be given except for institution-established emergency reasons.
- **Grade Adjustment:** If you dispute any scoring of a problem on an exam or homework set, you have one week from the date that the graded paper is returned to request a change in the grade. After this time, no further alterations will be considered. All requests for a change in grade in a homework must be submitted in writing to the TA and the instructor. All requests for a change in grade in an exam must be submitted in writing to the instructor.

- **Changes/Information:** The student is responsible for all assignments, changes of assignments, announcements, lecture notes, etc. All such changes should be posted on Blackboard.
- **Other:** As per university guidelines published in SCampus, the academic conduct policy will be upheld. You are required to study http://ee.usc.edu/sacss/ and the material linked there.

Grading Timeline

Homeworks will be graded within 1 week of submission and returned to the students. Results can be discussed during the office hours with the TA or instructor.

Additional Policies

Students are encouraged to collaborate and discuss homework sets with current classmates. However, each student has to write down their own solution independently and make sure to fully understand it. Exchanging solutions, using the solutions of a previous student of the course, finding solutions on the web, etc. are not allowed. Additionally, students are expected to not look at homework sets from previous students of the course. All your answers and assumptions should be clearly and fully justified. If we can't follow your thought process in your turned in assignment, points will be deducted even if your final answer is correct.

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings and Homework	Deliverable/ Due Dates
Week 1	Introduction to Integrated Circuits in Implantable Medical Devices	Readings: handouts and selected papers Homework: HW 1 out	
Week 2	Devices in CMOS technology; Review of MOSFET, basic amplifiers and current mirrors	Readings: handouts Homework: HW 2 out	HW 1 due
Week 3	Review of frequency response and feedback	Readings: handouts Homework: HW 3 out	HW 2 due
Week 4	Review of noise; Process variation in integrated circuits	Readings: handouts Homework: HW 4 out	HW 3 due
Week 5	Basics of Electrochemical methods	Readings: handouts Homework: HW 5 out	HW 4 due
Week 6	Introduction to neural interfaces Project Announcement	Readings: handouts and selected papers Homework: HW 6 out	HW 5 due
Week 7	Neural recording systems Midterm	Readings: handouts and selected papers Homework: HW 7 out	HW 6 due Midterm
Week 8	Circuit techniques in neural amplifiers	Readings: handouts Homework: HW 8 out	HW 7 due
Week 9	Neural stimulation systems	Readings: handouts and selected papers Homework: HW 9 out	HW 8 due
Week 10	Circuit techniques and safety concerns in neural stimulation	Readings: handouts Homework: HW 10 out	HW 9 due
Week 11	Clinical example: Visual, hearing and motor prosthetics	Readings: handouts and selected papers Homework: HW 11 out	HW 10 due Project Due: individual report
Week 12	Implantable biosensors	Readings: handouts and selected papers Homework: HW 12 out	HW 11 due
Week 13	Amperometric and potentiometric sensors	Readings: handouts Homework: HW 13 out	HW 12 due
Week 14	Clinical example: Glucose monitoring	Readings: handouts and selected papers	HW 13 due
Week 15	Trends in Implantable Medical Devices	Readings: handouts	Project Due: oral presentations and final report
FINAL			Date: For the date and time of the final for this class, consult the USC *Schedule of Classes* at classes.usc.edu/.

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

Support Systems:

Student Health Counseling Services - (213) 740-7711 – 24/7 on call
engemannshc.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-4900 – 24/7 on call
engemannshc.usc.edu/rsvp
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED) | Title IX - (213) 740-5086
equity.usc.edu, titleix.usc.edu
Information about how to get help or help a survivor of harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants. The university prohibits discrimination or harassment based on the following protected characteristics: race, color, national origin, ancestry, religion, sex, gender, gender identity, gender expression, sexual orientation, age, physical disability, medical condition, mental disability, marital status, pregnancy, veteran status, genetic information, and any other characteristic which may be specified in applicable laws and governmental regulations.

Bias Assessment Response and Support - (213) 740-2421
studentaffairs.usc.edu/bias-assessment-response-support
Avenue to report incidents of bias, hate crimes, and microaggressions for appropriate investigation and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Support and Advocacy - (213) 821-4710
studentaffairs.usc.edu/ssa
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.
Diversity at USC - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
dps.usc.edu, emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
dps.usc.edu
Non-emergency assistance or information.