

EE 411 – RF Integrated Circuits Design  
Fall-2022

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**RF Integrated Circuits - 10380 - EE 411 - 0**

**Scheduled Meeting Times**

**In-Class 03:40 pm - 05:30 pm T FENS L027**

**In-Class 08:40 am - 9:30 am R FASS G025**

**RF Integrated Circuits Lab. - 10382 - EE 411L - A1**

**Scheduled Meeting Times**

**Class 10:40 am - 12:30 pm R FENS G032**

- **Textbooks: RF Microelectronics (2nd Edition), *Behzad Razavi* (Required)**
- **The Design of CMOS Radio-Frequency Integrated Circuits, Thomas H. Lee (Strongly Suggested)**
- **Radio Frequency Integrated Circuit Design, J. W.M. Rogers and C. Plett [Suggested]**

**Prerequisite:** Analog Integrated Circuit Design and Intro. to RF

**Office Hour: 02:40pm – 03:30pm M (Instructor)**

**Office Hour: 12:40pm – 01:30pm R (TA)**

**It would be more convenient if you could send us email when coming at any time other than these hours.**

**Course Outcomes:**

A student who successfully fulfills the course requirements will be able to demonstrate:

- 1) To understand the concept of analog and RF integrated circuits technology, devices, components, using CMOS and SiGe BiCMOS technology, and their RF- models.

- 2) To understand fundamental design parameters of RF integrated circuits such as S-parameters, nonlinearity, sensitivity, efficiency, noise figure, input, output dynamic ranges etc.
- 3) To design matching and impedance transformation networks using in integrated circuits and components.
- 4) To understand fundamentals of the following RF integrated devices, circuits and systems: Low Noise Amplifiers, Mixers, Oscillators, Frequency Synthesizers, Power Amplifiers, Phase Shifters, Attenuators, Switch, Filters, etc.
- 5) To be able to analyze, design and simulate integrated RF circuits as such.
- 6) To be able to use and implement RF integrated circuits design and simulation tools such as ADS, Cadence Spectra, MOMENTUM.
- 7) To be able to understand RF integrated system specifications and breakdown these specs to building block and circuit levels.
- 8) To be able to measure and characterize RF integrated components and circuits.

### **Objectives:**

- 1) To understand the concept of RF integrated circuits
- 2) To analyze RF circuit building blocks building blocks (through lectures, homework and recitations)
- 3) To design these RF circuit building blocks (through lectures, homework and recitations.).
- 4) To design, simulate and optimize RF circuits with the aid of Cadence tools (through recit).
- 5) To design spiral inductors and transmission lines with the aid of SONNET tools (through recit).
- 6) To practice layout techniques in Cadence design environment (through recit).
- 7) To understand applications of RF circuits.

### **Summary of course content:**

- Overview of RF integrated circuits technology, III-V, CMOS, SiGe BiCMOS tech.
- RF and microwave SiGe BiCMOS transistor technologies and their RF-Models
- Fundamental design parameters of RF integrated circuits such as S-parameters, nonlinearity, sensitivity, efficiency, noise figure, input, output dynamic ranges etc.
- Matching and impedance transformation networks
- Detailed examination of each of the blocks in the transceiver architectures: Low Noise Amplifiers, Mixers, Oscillators, Frequency Synthesizers, and Power Amplifiers, Phase Shifters, Attenuators, Switches, etc.
- Theoretical and computer-aided analysis,
- Simulation and design of RF integrated circuits,
- RF integrated system specifications and breakdown these specs into building block and circuit levels.

## ***Seminar***

There will be two major projects in this course; a seminar talk that you will give on a topic you have researched, and a course project (discussed under Project). The seminar will be spread out in throughout the course. Please plan your schedule so that you do not end up being swamped at the end of the course.

Points to take note of:

- Your talk should last for at least 40 minutes.
- Your seminar will be a review of the state of the art of one topics. Some examples of such topics are:
  - Future of RF CMOS and BiCMOS fabrication and transistor technology, including SiGe BiCMOS, SOI-CMOS, CMOS technology and devices.
  - III-V Devices and technology RF Roadmap
  - Integration of microwave analog and digital systems
  - 5G/6G Front End Challenges: technology, device and circuits, along with integration and packaging perspectives
  - Performance enhancement for varactors, high Q, wider tuning range
  - Micromaching for silicon RF circuits
  - Substrate noise for RF Applications
  - Device crosstalk in silicon for RF Applications
  - RF MEMS for high speed systems
  - System-on-chip for RF Systems
  - You can also suggest topics, ...
- The topics can be any of the "theoretical" concepts that are to be covered in class
- Your topic should not be on a specific circuits like amplifiers, mixers, etc., as those will be used for the project
- The material covered in the seminar presentations is fair game for latter assignment questions.
- It is recommended that you prepare some slides beforehand. Please email your slides to the rest of the class, incl. us, a couple of days before your scheduled talk.
- You will be graded on your technical content and your presentation technique.
- All other students should come up with at *least* two questions for the presenter by the end of the talk as a question-and-answer session will follow the presentation. Everyone will be graded on their participation in the discussion.

## **Projects:**

There will be several numbers of design projects about RF Integrated Circuits topics like LNA, PA. These projects will be conducted by using cadence, ADS, sonnet etc.

The course project will be the second major task in EE 633/EE 411 (along with the seminar presentation). Your project should involve a literature review of the topic chosen, a discussion of the general topology, theoretical calculations showing the general operation, and simulation results using Cadence and supporting tools.

Several different performance metrics will be given (noise figure, power, area, linearity), and students will be ranked against one another in each category to determine an overall performance score. Most of the emphasis will be placed on having a well thought-out and justified design approach (i.e., analytical design rather than trial/error simulation game). Suggested topics are below;

- Low noise amplifier (common gate, common source, inductive degenerated, feedback, ...)
- Phase Shifter
- Mixers
- Attenuators
- VGA (current-steering,...)
- Single Pole Double Throw Switch ( $\lambda/4$  based, ...)
- Power amplifier (class A, class B, ...)

Sub-6 GHz and 24-30 GHz using SiGe BiCMOS and SOI-CMOS technologies are the topic of interest for this year as the project...

## **Progress and Final Report**

The course project is to be submitted for marks in the form of a final report, as well as all electronic materials. The final report is to include all of the design procedure, calculations, citations, and simulated results.

You will also present the final results of your project in class at the end of the course. This will be a 30 minutes summary (including time for questions), and should include the same items as your report (though with less detail).

Note that you will be graded on technical content, the written format and style, and the oral presentation style.

There will also be at least two short progress report and presentations until the final due date of the project.

### **Exams:**

There will be a midterm and final exam.

### **Grading:**

Assignments (or Quiz) total . . . . . 15 %

Projects (incl. seminar). . . . . 35 %

    Seminar: 10 %, Project in total 25%, and will be divided into 2 progress report/presentation, with 5 % for each, and final report and presentation is 10%.

Midterm . . . . . 25 %

Final Exam . . . . . 25 %

**Late Policy:**

No late homework assignments or projects will be accepted.

**Tentative Lecture Topics:**

Introduction, Applications, RF Transceiver Overview

RFIC Devices and Technology

RF Concepts: Passive RLC Networks, Smith Chart

RF Concepts: Nonlinearity

RF Concepts: Noise

RF Concepts: Sensitivity, Dynamic Range

RF Integrated Circuits: Low Noise Amplifiers (LNA)

**Midterm Exam**

RF Integrated Circuits: Power Amplifiers (PA)

RF Integrated Circuits: Mixers

RF Integrated Circuits: Voltage Controlled Oscillators (VCO)

RF Integrated Circuits: Phase Shifter (PS)

RF Integrated Circuits: Attenuators (ATT)

RF Integrated Circuits: Variable Gain Amplifier (VGA)

RF Integrated Circuits: Single Pole Double Throw Switch (SPDT)

RF Concepts: Modulation

Architectures: Receivers

Architectures: Transmitters

RF Integrated Circuits: Frequency Synthesis (PLL)

**Final Exam**

Instructor has right to change grading policy after announcing in the class.

Make-up for final and midterm exams will only be offered to students who produce officially accepted valid excuses. Otherwise, students cannot have make-up option.

The due date of the homework/project is one week later from the assignment date, unless otherwise stated.

**Late project/Homework submissions will be penalized 25% for first 6 hours and 50% for the first 24 hours. Late project submissions more than 24 hours will not be accepted.**

Discussion on homework/project assignments is encouraged. Turning in identical homework/project solutions is considered cheating.

Cheating in exams and project will **NOT** be tolerated and will be subjected to disciplinary action.

Attendance will be taken randomly according to YOK regulations.

## **Last Words of the first Lecture**

**I hope that you find the course enjoyable and rewarding in terms of the learning experience.**

**Keys to success in the course are:**

- 1) Good time management - designate fixed time slots in your schedule for watching the lectures and doing the guided cadence-software assignments.**
- 2) Keep yourself "in sync" with the rest of the class - don't allow material to accumulate.**
- 3) Work independently on the homework projects - this hands-on experience is crucial for fully understanding the theory.**
- 4) Keep open channels of communication with the course instructor (and TAs) - e-mail, call on the phone or visit during office hours.**
- 5) Never allow yourself to "get stuck" on a homework problem - seek help. You may do it by e-mailing the professor and make sure to include your problem statement clearly.**
- 6) Whenever you feel "stuck" reading the theory or doing the hands-on assignments, try to articulate in words what exactly it is that you don't understand. Then e-mail your questions. You may also write your questions on a "post-it" notes, tacked to the appropriate written notes locations. When you come to an office hour visit, we may go through your specific questions one-by-one.**
- 7) Make Recitations/Office Hours more productive, if you take the effort, ahead of the meeting, to do some preliminary work, and have some specific questions.**

- 8) Allow at least an hour or two a week to go over recommended practice exercises from the book.
- 9) Always keep a "cool head" during exams. Exam questions will never be tricky. They are designed only to assess your knowledge in a straightforward manner, and reward you if you did all the homework and went through the practice exercises.
- 10) When preparing for an exam, don't skip topics. Announcements will be very explicit regarding test topics. Typically, exams attempt to cover ALL topics. Every one of the problems may feature a mix of several topics.
- 11) We provide formula paper in advance of the exam. But you will not have enough time to find right formula or understand the formula "in real-time" during exams. Come well organized - know exactly where / what each given formulas are.
- 12) Always bring your calculator to exams. All problems will feature real circuits with real-life component values. Therefore you should not expect the numerical answers to always be "nice numbers".
- 13) Keep in mind that in the field of Electronics, most formulas are rarely "global". Circuit modifications (i.e. adding a load, adding source resistance etc.) may cause some of the formulas to slightly change appearance. Try always to grasp the ideas behind each formula. Then apply the ideas to modify the formulas to fit a new circuit. Don't blindly substitute numbers into any formula that catches your eye.