Communication Electronics

ECE145B/ECE218B - Spring 2008

University of California, Santa Barbara

TR 2 – 3:15, Bldg 387, Room 103

Course contents. See the syllabus below. The course explores the design and analysis of radio frequency circuits and the corresponding measurement techniques. Mixers, voltage controlled oscillators, receivers, and phase locked loops are studied this quarter.

ECE145B and ECE218B are co-listed in the catalog. Graduate students should enroll in 218B.

Prerequisite: ECE145A/218A or permission of instructor. You must be familiar with transmission lines, Smith Chart, matching network design, amplifier gain, stability, noise figure, distortion in nonlinear systems. You should also have a basic knowledge of the use of Agilent ADS simulation tools.

Instructor: Prof. Stephen I. Long, 2231F Engineering Sciences Building, 893-3965, long@ece.ucsb.edu
Office hours: Tues/Thurs 3:15-4:30 or by appointment.

Teaching Assistants: Lakshmanan Nataraj (lakshmanan_nataraj@umail.ucsb.edu) and Alex Medina (alexmedina@umail.ucsb.edu). A third TA, PilJae Park (coolpj@ece.ucsb.edu , will only be available to assist with the RFIC project. Office hours (to be held in the lab) TBA.

References: I have selected a textbook that is an excellent reference. This book gives lots of insight but is weak on analysis. For those of you who are truly interested in the subject, it will prove to be a valuable investment. I will pick a few chapters from the book for reading during the quarter. But, if you are on a tight budget, or just taking the class to satisfy a series requirement, you can get along ok by reading the lecture notes and the supplementary reading materials.

1. T. H. Lee, *The Design of CMOS Radio-Frequency Integrated Circuits*, Second Edition. Cambridge Univ. Press, 2004.

2. ECE145B/218B reader. (Alternative, 6556 Pardall Rd, Isla Vista.). This and the lecture notes will be the primary source for reading material.

3. Lecture notes, data sheets, application notes, ADS simulation files and tutorials will be posted on the course web page:
www.ece.ucsb.edu/~long/
I tend to update lecture notes as we go along, so don't print them out before we need to use them.

Tools: Each lab group will be provided with a toolbox. The components and tools (expensive! handle with care) will be checked out by the ECE electronics shop. You will be responsible for returning these in good working order. Don't leave the toolbox sitting in the lab. Last year, one box was stolen.

Reserve Book Room.
Homework solutions will be placed on the RBR library web site: eres.library.ucsb.edu. There will be other readings and reference materials available there as well.

Grading. The grading for seniors and graduate students will be separate. Graduate students taking the course will be assigned more difficult projects. The final is on Tuesday, June 12, 4-7pm. The grade for this course will be based on the following:

Lab Projects	40%
145B: (lab1: 5%; lab2 10%; lab3 25%)	
218B: (lab1: 5%; lab2 20%; lab3 15%)	
Final	30%
Midterm	20%
Homework	10%

Laboratory projects:

#	project	Course	Start	Checkout and/or report due
1	**Mixer characterization**	**145B, 218B**	**4/1**	**4/11**
2	**RFIC layout and design review**	**218B**	**4/15**	**5/16**
2	**VCO**	**145B**	**4/15**	**5/2**
3	**Receiver design project**	**145B**	**5/8**	**6/6**
3	**PLL Frequency Synthesizer+VCO**	**218B**	**5/16**	**6/6**

Group presentations on one of the design projects will be required.

Laboratory: The lab is in room 5162D. It will be accessible by card key. You may work in teams of two (preferred) or three (only if absolutely necessary) for the lab projects. A single report for the team will be sufficient.

Project checkout. Design projects (ECE145B/Labs 2 & 3; ECE218B Lab 3) must be demonstrated to the TA or instructor to verify that all specifications are met. You will need to make an appointment with the TA when you are ready to checkout. The RFIC project will require a design review presentation.

Tools: Each lab group will be provided with a toolbox. The components and tools (expensive! handle with care) will be checked out by the ECE electronics shop. You will be responsible for returning these in good working order. Your BARC account will be charged for anything missing.

Notebooks: Each student will be expected to maintain a lab notebook. Pages should be numbered and entries dated that document activity on the lab projects. Handwritten and computer plotted or generated measured data should be kept in the notebook. Keeping a sequential record of your work is an important discipline to acquire. Its purpose is twofold:

1. It provides a written record of your design process that can help you recall effective solutions to design problems and can help you avoid making the same mistakes again.
2. Many companies make lots of money on patents. New ideas must be documented by written, sequential, dated records in order to qualify for patent. Patent applications are very time sensitive, and properly documented notebooks play a central role in establishing date of concept. (In most cases, a bound notebook is required, but computer generated data is more easily included in an open notebook. Since you won't be filing for a patent on our projects, it is ok to use a 3 ring binder, but do number and date pages).

The notebook can contain circuit analysis work, design alternatives, ADS printouts, diagrams, measured data, or anything that seems relevant at the time. Incorrect or ineffective approaches and ideas should not be erased. You may want to refer back to something previously done.

Lab Reports: Writing ability is a vitally important skill for an engineer. Your ability to clearly and concisely present your work in a formal manner to those who sponsor it, or the ability to clearly describe a proposed plan of action in order to obtain the necessary funding will play more of a role in your success as an engineer than most of you would imagine. Unfortunately, many engineers haven't made the effort to learn the necessary skills. Formal lab reports on the design projects will be required in order to help you improve your writing and communication skills.[1]

Grading Standards

The standards for grading of the design projects are as follows. Please refer to the report format below to understand expectations.

Seniors

A	Project meets all expectations. Report is well organized and written.
A- , B+	Project comes close to meeting expectations; report is well organized and written, or the project meets expectations but the report is lacking in one component.
B	Project comes close to meeting expectations; report is lacking in two components.
B - , C+	The project is adequate, but is poorly documented in the report.
C, C -	Project doesn't work or is incomplete.
F	Project bursts into flames during demo and burns TAs hand, or no project and report is submitted.

Graduate Students

A	Project exceeds expectations. Report shows evidence of exceptional understanding. Innovative approaches were successfully employed at some point in the design.
A-	Project meets all expectations. Report is well organized and written.
B+	Project comes close to meeting expectations, and report is well organized and written .
B - C+	The project meets expectations, but is poorly documented in the report.
C	Project doesn't work or is incomplete.
F	Project bursts into flames during demo and burns TAs hand, or no project and report is submitted.

Lab report format

All labs this quarter are design labs. We will be looking for each of the items listed below. The report should be organized in such a way that the reader can clearly follow your discussion and see the connections between your design, analysis, and the performance characterization.

1. **Title page**.

[1] If you need help with your writing skills, there is an excellent, short, and entertaining book available: W. Strunk and E.B. White, The Elements of Style, Third Edition, Macmillan Publishing Co., New York, 1979.

2. **Introduction.** Describe the objectives of the experiment and summarize the approach taken. Design specifications should be presented here as well.

3. **Analysis and Implementation.** Present the circuit in overview (block diagram) and describe the function of each important circuit block. Present the analysis and design equations used for each part of the design. Include any assumptions made, and discuss tradeoffs that affected your design choices. Schematic diagrams and description and evaluations of any unusual components should be included. Second generation design improvements should be discussed.

4. **Performance.** Describe the measurement methods used to evaluate your project, and discuss any important factors that influenced your measurements. Summarize the results of your measurements and compare the results to the specifications, calculations and simulations. Attempt to explain any discrepancies. Note that tables of raw data should not be in the report; they should be found in your notebook. But, graphs or summary tables of the results may enhance the presentation and should be included in the report when appropriate.

5. **Cost analysis and power dissipation**. Make an estimate of the cost to build the final design in moderate volume (1000 units). Measure the power dissipation. Include these in your report for 5% of the report grade.

6. **Conclusions**. This section should identify which part of the experiment was most difficult and why. Identify unresolved problems that arose, and suggest ways to solve them if time permitted. Finally, if you have some ideas on how the experiment or circuit could be further improved, suggest them here.

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Syllabus: ECE145B/218B Spring 2008

Date	**Topic**	*Reading*, **lab**

Reading assignments are from the textbook, lecture notes or the selected readings

I. Review from 145A/218A

	Superheterodyne and direct conv. architecture	
	images, spurs, single and dual conversion	*Intro to receivers*

II. Mixer design and characterization

4/1	Introduction to mixer design.	*Mixer Notes 1*
	Active vs. passive; nonlinear vs. switching	**Mixer lab #1**
	Single and double balanced mixer. Mixer IMD	
4/3	Gilbert multiplier. Mixer dynamic range; NF.	*Stanford Ch6; Lee Ch. 13.*

For a good exposition of quadrature signals and image rejection, follow the link, download and read:
Quadrature Signals: Complex, But Not Complicated, by Richard Lyons.
http://www.dspguru.com/info/tutor/quadsig.htm

4/8	Quadrature signals and image rejection	
	phase shifters and polyphase filters	*Razavi 5.2.3*
4/10	Sonnet EM simulation software tutorial	
4/11		**Mixer lab due**

III. Oscillator design

4/15	Resonator analysis. Tapped C and L impedance transformers.	*Stanford, Chap. 4; Lee Ch 3*
	Oscillators: FB model;	*Oscillator Notes 1*
		Lab2 begins
4/17	tuned amp . LC oscillators: cross-coupled; Colpitts.	
	Open loop analysis, tank impedance; amplitude limits	*Lee, Chap. 17*
4/22	Colpitts oscillator: biasing, output buffer; varactor tuning	*Oscillator Notes 2*

	ADS oscillator simulation.	ADS oscillator sim
4/24	Crystal oscillator . negative resistance oscillators,	
	Ring oscillator.	*Oscillator Notes 2*
IV. Frequency compensation of feedback amplifiers		*G/M:8.5,9.1-9.5*
4/29	Feedback. amplifier configurations	*Lee: Chap 14*
		Feedback Notes 1
5/1	FB frequency response. Stability, second-order lowpass systems,	
	phase margin, damping factor; step response	*Feedback Notes 2*
5/2		**145B: Lab2 due;**
5/6	**MIDTERM EXAM**	
5/8		**145B:Lab 3 begins**
5/8	compensation of feedback systems.	*Feedback Notes 2*
V. Frequency modulation;		
5/8	FM Receivers; quad demodulator	*Haykin 2.6,2.7*
VI. Phase locked loops and their applications.		*Lee: Chap. 16;*
5/13	Intro to PLL feedback systems, Second order loops.	*PLL Notes 1*
5/15	Phase error. PLL FM demodulator	*G/M 10.4*
	Frequency synthesizer analysis, type 2 loop filter	
5/16	**218B:RFIC des.review;-lab3 begin**	
5/20	phase frequency detector, Reference spurs, charge pump loop filter,	
5/22	capture, Third order PLL	*PLL Notes 2*
5/27	phase noise filtering, synthesizer architectures	
5/29	Phase noise – Leeson's model. Impulse sensitivity function.	*Lee, Chap. 18*
	Design of low noise oscillators: Tapped L; Clapp Oscillator.	
Last Week:		
6/3	Lab 3 discussion session	
6/5	CE/EE capstone project forum	
6/6	145B Lab 3 project presentations	
6/5, 6/6	**Lab 3 checkout;**	**145b, 218b Lab 3 reports due 6/6**
6/10	**FINAL EXAM**	**Tuesday, 4-7pm**

revised 3/21/08

Course outcomes – core competencies to be acquired in ECE145B/218B

I. Receivers: Understand images, noise figure, intercept point and their relationship to receiver performance. Single and dual conversion. Direct conversion and superhet.
II. Mixer design and characterization: Understand mixer modes of operation, balancing, conversion gain, image rejection and quadrature signals.
III. Oscillator design: Understand resonators, tapped L and C impedance transformers, analysis of oscillators- both feedback and negative resistance, varactor tuning, LO buffer amplifiers.
IV. Frequency compensation of feedback amplifiers: Understand how to analyze the 4 topologies of feedback amplifier, predict stability of feedback amplifiers with phase margin and root locus plots, and know how to apply basic FB compensation techniques.
V. Phase locked loops and their applications: Understand how a PLL works, how to analyze it using linear feedback system methods, design of appropriate loop filter, applications to FM demodulation and frequency synthesis.