Communication Electronics
ECE145B/ECE218B - Winter 2011
University of California, Santa Barbara
MW 3:30 - 4:45, ESB 1003 (Cooper Lab)

Course contents. See the syllabus below. The course explores the design and analysis of radio frequency circuits, systems and the corresponding measurement techniques. Receiver system performance, mixers, voltage controlled oscillators, 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 should be familiar with transmission lines, Smith Chart, matching network design, amplifier gain, stability, noise figure. You should also have a basic knowledge of the use of Agilent ADS simulation tools.

Instructor: Prof. Stephen I. Long, 3221F Engineering Sciences Building, 893-3965, long@ece.ucsb.edu
Office hours: MW2 - 3 or by appointment.

Teaching Assistant: TBA; Office hours (to be held in the lab)

References: The primary references are the lecture notes and the supplemental readings.

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

2. 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.

3. T. H. Lee, *The Design of CMOS Radio-Frequency Integrated Circuits*, Second Edition. Cambridge Univ. Press, 2004. I have selected this 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.

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..

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 have more difficult assignments. The final is on Tuesday, June 9, 4-7pm. The grade for this course will be based on the following:

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

Laboratory projects:

#	project	Start	Checkout	Report due
1	**Large signal amp and mixer characterization**	**1/5**		**1/24**
2	**VCO**	**1/26**	**2/16&17**	**2/18**
3	**PLL Frequency Synthesizer**	**2/23**	**3/10&11**	**3/14**

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 (Labs 2 & 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. At the end of the quarter you will need to give a presentation on one of the design projects.

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 for design labs (2 & 3)
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**.

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.

[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.

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 Winter 2011

Date	**Topic**	*Lecture Notes*, **lab,** Supplement
Reading assignments are from the textbook, lecture notes or the selected readings		
I. Receiver Systems		
1/3	Distortion and Noise	*Distortion and Noise* pp.1-9;15-30
	Gain compression, Intermodulation;	
	signal-to-noise ratio;	
	Intercept and NF of cascaded stages; MDS; SFDR.	
1/5	LNA design: 2 port noise parameters	*LNA Design* pp.1-22
	noise figure and available gain circles	*ADS Tutorial: NF Analysis*
	ADS NF simulation. Design procedure	**Large Signal Lab**
1/10	Receiver systems. frequency translation	*Intro to receivers*
	Superheterodyne and direct conv. architectures	Razavi pp.122-146
	images, spurs, single and dual conversion	Pozar pp. 111-131
II. Mixer design and characterization		
1/12	Introduction to mixer design.	*Mixer Notes 1*
	Active vs. passive; nonlinear vs. switching	**Mixer lab**
	Single and double balanced mixer. Mixer IMD	Analog multipliers
1/19	Gilbert multiplier. Mixer dynamic range; NF.	Stanford Ch6; Lee Ch. 13.
1/24	Quadrature signals and image rejection	*Mixer Notes 2*
	phase shifters	

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

1/24		**LS and Mixer labs due**
III. Oscillator design		
1/26	Resonator analysis.	*Resonators and Q*
		Oscillator Notes 1
	Tapped C and L impedance transformers.	Stanford Chap. 4; Lee Ch 3
		Lab2 begins
1/31	Oscillators: FB model; tuned amp .	
	LC oscillators: cross-coupled; Colpitts.	*ADS sim. of oscillators*
	Oscillator simulation methods	Lee, Chap. 17
2/2	Colpitts oscillator: biasing, output buffer;	*Oscillator Notes 2*
	varactor tuning	
2/7	**MIDTERM EXAM**	

2/9	Crystal oscillator . negative resistance oscillators, Ring oscillator.	
IV. Frequency compensation of feedback amplifiers		G/M: 9.1-9.5; Lee: Chap 14
2/14	FB freq response. Stability, second-order lowpass, phase margin, damping factor; step response compensation of feedback systems.	*Feedback Notes*
2/18		**Lab2 due;**
V. Phase locked loops and Frequency Synthesis.		Lee: Chap. 16;
2/16	Intro to PLL feedback systems, Second order loops.	*PLL Notes 1*
2/23	Phase error. Frequency synthesizer analysis, type 2 loop filter, phase frequency detector, Reference spurs, charge pump loop filter	**Lab3 begin** Razavi Ch 15
2/28	phase noise filtering, Third order PLL, PLL Simulation using ADS	*PLL Notes 2*
3/2	Synthesizer architectures. Delay locked loop Phase noise – Leeson's model.	
Last Week: Intro to Power Amplifier Design		
3/7	Power amplifiers:	PA Notes #1
3/9	Power amplifiers	PA Notes #2
3/11	Lab 3 project presentations	
3/10, 3/11	**Lab 3 checkout;**	**Lab 3 reports due 3/14**
3/19	**FINAL EXAM**	**Saturday, 12-3 pm**

revised 12/10/10

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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 frequency synthesis.