Communication Electronics Winter 2007
ECE145A/ECE218A
University of California, Santa Barbara

Course contents. See the syllabus attached. The course explores the design and analysis of high frequency circuits (1 MHz to 2 GHz) and the corresponding measurement techniques. Communication receivers will be used as a vehicle to focus this potentially broad topic. While the fall quarter course is self-contained, a lot of the material is foundational in nature. It is necessary to take the two quarter sequence to complete the study of the receiver and to obtain a full design experience.

ECE145A and ECE218A are co-listed in the catalog. Graduate students should enroll in 218A.

Hours. MW 12:30 – 1:45. 1437 Phelps Hall. Although the catalog lists a scheduled lab time, the lab is open by card key access at all times. The scheduled times will be used only for TA office hours and equipment demos.

Instructor: Prof. Stephen I. Long, 2231F Engineering Sciences Building, 893-3965, long@ece.ucsb.edu
Office hours: M2-4; Thurs 2-4.

Teaching Assistants: Arman Matinyan; Rajeev Rao. Office hours TBD (to be held in the lab).
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References:

1. Textbook: Textbook: G. Gonzalez, Microwave Transistor Amplifiers: Analysis and Design, Second Edition, Prentice-Hall, 1997. This will be the primary reading source.

2. ECE145A lecture notes. Lecture notes are on the ECE145A/218A web page: http://xanadu.ece.ucsb.edu/~long. Supplemental reading materials are in the RBR or on the electronic RBR web site.

3. RF Prototyping Techniques and Inductor Construction Guidelines. Past experience has shown that most problems with the laboratory assignments are caused by lack of knowledge and experience in prototyping methods suitable for high frequency design. These extensive guidelines are available as pdf files that can be downloaded from the web. Another advice: complete the design and simulate your results before you start to build! These projects can't be done by trial and error.

4. One additional reference is recommended, C. Bowick, *RF Circuit Design,* Newnes, reprint edition 1997. This is a practical book with good examples on the use of the Smith Chart for designing matching networks and amplifiers. Some students in the past have said that it is very helpful. It is available from Amazon. The section on impedance matching is on the eres website.

Design Tools. We will be making extensive use of Agilent ADS. This is available on the ECE PCs and Unix workstations in the ECI lab and on the PCs in 5162D. Tutorial information can be found on the course web. Sonnet will be used for electromagnetic modeling of transmission line structures and spiral inductors.

Prerequisite: ECE137AB or equivalent undergrad electronics course. (B- or higher grade in these classes is NECESSARY if you hope to get anything out of 145A). Students are expected to be familiar with device small signal models, transistor biasing, analysis of gain and frequency response of multistage amplifiers by small signal methods, feedback concepts.

Laboratory projects:

Assignment #1: Network Analyzer

use of NA, characterization of components, transmission lines.

Assignment #2: Characterization of wideband RF amplifier

Use of Spectrum Analyzer. Characterize gain compression, harmonic and intermod distortion.

Assignment #3: Narrowband Low Noise Amplifier Design and Evaluation

Grading. The grading for seniors and graduate students will be separate. Graduate students taking the course will be assigned more difficult projects and occasionally additional homework or exam problems. The grade for this course will be based on the following:

Lab Projects	40%
Lab 1: 8%; Lab 2: 12%; Lab 3: 20%	
Final	30%
Midterm	20%
Homework	10%

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. Team members must be enrolled in the same course.

Project checkout. Design projects (ECE145A/Lab3; ECE218A/Labs2 and 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.

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]

[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.

Grading Standards

A. Lab 1

This is intended as an introduction to network analyzer usage, measurement techniques, and prototyping. A report will be required, but need not be as detailed as the design project reports. Plots of measured data along with a concise description or explanations as needed will be sufficient.

B. Design Projects

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

All design projects must be presented to the TA for final checkout to demonstrate their performance.

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 TA’s 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 TA’s hand, or no project and report is submitted.

Design Lab report format

As you can see above, a well written lab report can significantly improve your grade. 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. If you considered alternate solutions that do not appear in the report, make reference to the pages in your notebook describing this work. Copies of relevant notebook pages or the original should be submitted with the report.

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 tables that summarize or clearly present the results should be included in the report.

5. **Cost analysis and power dissipation**. Economic factors always influence engineering design. 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.

6. **Sensitivity of design to parameter variations.** The cost of manufacturing will often depend on the adoption of a robust design – one that is tolerant to reasonable variations in components and temperature. Describe the sensitivity of your design to small variation in the device or components, and temperature if the models include temperature dependence. You may use ADS to perform this in simulation by sweeping component values as a parameter.

7. **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.

Reserve Book Room. The following materials can be found on the library reserve book website. http://eres.library.ucsb.edu/.

1. EE344 Chapter 1 (Stanford Notes) Nonideal Components
2. Tektronix App. Note: Spectrum Analyzer Fundamentals
3. C. Bowick, *RF Circuit Design*, Chap. 4, "Impedance Matching," Butterworth-Heinemann, 1982.
4. Homework Solutions

Also, paper materials are available on 2 hour loan:
1. EE344 High Frequency Laboratory, Stanford University, 1995.

Lectures ECE145A/ECE218A WINTER 2007 [2]

I. Transmission lines and two port s-parameters	**Date**	**Activity**
1. Introduction and lumped components at RF.	1/8	Read Bowick pp. 9-30
R, L, C, Q		or Stanford Chap. 1
2. Transmission lines	1/10	Read G. 1.1-1.6, 1.9
structures, ideal and lossy lines		
forward & reflected waves, reflection coefficient		
terminations: load, short, open		
transmission coefficient at source; between trans. Lines		Read G. 2.1 – 2.3;
3. Transmission lines	1/12	**(FRIDAY)**
Position dependence of Z, gamma		Network analyzer orientation
Smith Chart - plot Z on chart		**LAB #1 Assigned**

[2] This represents my best guess for the syllabus at this time. It is entirely possible that changes will be made during the quarter.

Quarter-wave line example		Read: ADS Tutorial: Basics
HOLIDAY	1/15	
4. Transmission lines:	1/17	
Admittance chart		
Two port parameters (y, z, h, and s-parameters)		
5. Matching network examples	1/22	Read G. 2.4
Impedance Matching Techniques		
L network		alternate reference: Bowick, Impedance Matching
6. Matching networks		on eres website
distributed matching networks	1/24	Read G. 2.5
<u>II. Performance Limitations of Amplifiers</u>		
7. Performance limitations part 1: distortion	1/26	**(FRIDAY)**
Gain compression, IMD, HD, Intercept point		
8. IP cascading, two-tone simulations,	1/29	**LAB 1 Due; LAB 2 Assigned.**
HB tutorial; intro to spectrum analyzer		Read: Harmonic Balance Tutorial
9. Performance limitations part 2: noise	1/31	
sources of noise*;* noise models		
Signal-to-noise ratio; noise figure; noise bandwidth,		
NF cascading; noise temperature.		
NO CLASS	**2/5**	
		<u>MIDTERM EXAM (Feb. 7)</u>
III. <u>Amplifier Design</u>		
10. Amplifier design (2 port parameter approach)	2/12	Read G. 2.6 – 2.8; 3.1 – 3.3
stability analysis, circles,		
stabilization methods		
VSWR and gain definitions		
11. input and output match, gain circles	2/14	Read: Gain and Stability Tutorial
unilateral approximation		
bilateral case, conjugate match conditions		
max. stable gain, Gp circles.		
	2/16	**LAB 2 due.**
HOLIDAY	2/19	
12. bias circuit design, matching circuits,	2/21	Read G. 3.4 – 3.7, 3.9
wideband stability analysis,		
Implementation issues.		**LAB 3 Assignment**
13. Design of low noise amplifiers:	2/26	Read: ADS Noise Figure Tutorial
Two port noise parameter approach		Read G. 4.1 – 4.3
sources of noise*;* noise and Ga circles;		
14. ADS noise modeling; noise figure measurements	2/28	
<u>IV. Intro to receivers</u>		
15. Receiver system basics	3/5	**LAB 3 Due.**
Free space radio propagation model		
mixers: frequency conversion; channel selection		
Image rejection		
16. Receiver system architectures	3/7	
single and dual conversion		
direct conversion vs. superhet vs. low IF		
receiver performance metrics: MDS, IP2 & 3, SFDR, BDR		
reciprocal mixing		
17. Mixer basics	3/12	
switching vs. nonlinear mixing		
balancing to reduce spurs		
Diode and FET passive mixers		
18. Active mixers	3/14	
DSB and SSB noise figure		
Gilbert cell double balanced mixer		

19. Q/A session for review for final. 3/16 **FRIDAY**

FINAL EXAM **3/21 12 – 3pm**

Revised 12/12/06

University of California, Santa Barbara

Department of Electrical and Computer Engineering

Course Syllabus

ECE145A *Communication Electronics* 5 units

Catalog Description:
Analog communication circuits 1 MHz to 2 GHz with emphasis on receivers. S parameter design techniques, nonideal components, distortion, low noise amplifier design and characterization , system level analysis.

Prerequisites: ECE137AB

Text, References, and Software:
G. Gonzalez, Microwave Transistor Amplifiers: Analysis and Design, Second Edition, Prentice-Hall, 1997
ECE145A lecture notes (on web site: mail.ece.ucsb.edu/~long)
Agilent Advanced Design System (ADS) and Sonnet Software simulation tools

Course Goals:

1. Transmission Lines and Lumped Components
    1. Use S parameters and the Smith Chart for design of lumped element and distributed L matching networks
    2. Able to model (Agilent ADS, Sonnet) and measure (network analyzer) nonideal lumped components and transmission lines at high frequencies
2. Amplifier performance metrics
    1. Analysis of large signal limitations of amplifiers: gain compression, harmonic and intermodulation distortion.
    2. Use harmonic balance simulation to predict large signal limitations
    3. Familiar with the use of signal to noise ratio, noise figure, noise temperature, and the measurement and simulation of noise figure
3. Small Signal Amplifiers:
    1. Able to use network analyzer to measure gain and phase of amplifiers
    2. Derive gain, reflection, and transmission coefficients.
    3. Use S-parameters with gain and stability circles to design and build stable bandpass amplifiers.
    4. Familiar with the use of signal to noise ratio, noise figure, noise temperature, and the measurement and simulation of noise figure.
    5. Able to use two-port noise parameters, noise and available gain circles to analyze, design, build and test a low noise amplifier. Use of noise figure measurement equipment.
    6. Able to design stable DC bias circuits for amplifiers
    7. Use spectrum analyzer to measure gain compression, harmonic and intermodulation distortion.
4. Receiver Systems:
    1. Use of mixers for frequency conversion
    2. Understand MDS, images, noise figure, intercept points, dynamic range and their relationship to receiver performance.
    3. Strengths and weaknesses of direct conversion vs. superhetrodyne architectures.