University of California, Santa Cruz
Electrical Engineering Department
EE-157 & 157L, Winter 2015

RF Hardware Design

Lecture Room: Kresge 325, MWF 11:00 – 12:10pm
Laboratory Room: BE161
Instructor: S.C. Petersen (petersen@soe.ucsc.edu)
Office: BE251 (x9-4782)

Course Description:

This course discusses the design and construction of passive and active electronic circuits necessary to the engineering design and realization of modern wireless circuits employing “radio frequencies” (RF) as part of a larger “wireless” system.

We will begin with a system-level discussion of the uniquely important engineering challenges that every wireless system must address. This will develop the background and establish a perspective to fully understand various hardware circuits of all types along with various parameters of merit. This includes LNA’s, mixers, IF amplifiers and demodulators; impedance matching, noise factor and noise figure.

Our work will also discuss how active and passive RF hardware is implemented on printed circuit boards. Wireless interconnections using RF require an understanding of both lumped and distributed circuit theory. Unlike low-frequency circuits, where the non-ideal effects of lumped passive circuit elements can usually safely be neglected, like resistors, capacitors, inductors and even wire, RF design requires that special attention be paid to them. Also, because propagation times become significant, we must carefully account for the effects that travelling electromagnetic waves now play, and will spend considerable time on the characteristics of these so-called distributed circuits, covering time-harmonic transmission line theory and classical antenna structures.

Analysis and design tools will be added to your repertoire of skills. Conventional linear n-port matrix models will be addressed, including ABCD and scattering parameters (S-parameters), a technique developed by Hewlett Packard engineers in the 1950’s. S-Parameters are naturally integrated with a famous graphic tool for use primarily with distributed circuits: the venerable Smith Chart, and we will treat this wonderful tool completely. Non-linear topics include oscillator design and implementation, and Class B, C, D and E amplifier topologies.

Relevant system-level topics, like modulation, SNR, link loss and the like will be treated in context to provide an understandable basis for *why* circuits are designed as they are. Modern techniques involving mixed-signal design, i.e. those involving digital and analog circuits, especially those applicable to so-called modern “software defined radios” (SDR) will be surveyed. This topic centers principally on A/D and D/A circuits.

Since it is the instructor’s belief that competent RF engineering design requires mastery of *both* theoretical and experimental aspects, accompanying laboratory work will provide students with significant hands-on experience. The early laboratories will aim at developing essential insight and intuition as prerequisites to understanding RF hardware analysis and design, and will specifically introduce the following essential pieces of test equipment: RF spectrum analyzer; RF network analyzer; RF signal generator and vector network analyzer. Students will gain balanced skills working in both the time and frequency domains. Since the lecture and laboratory are closely related, enrollment in both,

All students are expected to be competent in fundamental electrical lumped-circuit theory (EE101 or equiv.); possess a basic grasp of open-loop BJT and FET circuits (EE171 or equiv.), and know how to draw engineering schematics and translate these into workable prototype printed-circuits (EE174 or equiv.). A first course in digital design (CMPE100) and microprocessor system design (CMPE121) is recommended and quite helpful, but are not required. These latter courses provide breadth and depth of understanding, since most modern RF systems typically include microcontrollers and any associated digital logic.

References:

The books I have chosen for our class are not intended to serve as "textbooks" in the classical sense. Rather, they are meant to introduce you to the need for valuable *references* for RF hardware design and analysis and to begin acquiring your own. Practicing RF engineers generally have fairly large libraries of such books and related papers. (I am no exception; indeed all of these come from my own library). References teach you *approaches* to various problems, rather than enumerate vacuous canonical methods that formalistic textbooks typically offer. Instead, I want to expose you directly to things that you can actually design and build *now* rather than off in the hypothetical future. Hence, faced with real design problems, we pore over these references and decide what's relevant to extract from them. I believe this kind of exposure is much more enjoyable and motivating and, basically, defines the focus of our course, viz. the engineering design of real RF hardware. References, then, have much broader coverage and are generally less cluttered with formally theoretical material. We keep our focus on *relevant* design and analysis techniques in favor of detailed bottom-up but largely irrelevant discussions. These latter topics can always be found in appropriate textbook references, and you will certainly often want to refer to them. Indeed, I will include some of them - but they will be listed as part of a larger theoretical bibliography and I won't require that you purchase any of them. I will however use several chapters from some of these that deal with absolutely essential theoretical foundation material: notably, distributed circuit theory enabling us to competently work with transmission lines and antennas; theory of noise; oscillator design fundamentals; specialized solid-state devices that will pleasantly extend your knowledge beyond EE171.

Books you will need now:

1. RF Circuit Design, by Chris Bowick; Newnes Elsevier 2nd Ed., 2008.
   Available on Amazon. New for about $47; many used sources also listed.

2. Experimental Methods in RF Design by Wes Hayward, W7ZOI et. al. American Radio Relay League, 1st ed. 2nd printing (revised first ed.), 2003. Obtain this book directly from ARRL at:
   http://www.arrl.org/shop/Experimental-Methods-in-RF-Design

Additional books / references.

3. RF Circuit Design, Theory and Applications, Ludwig and Boggdanov, Pearson Prentice Hall 2nd ed. 2009.

   This book plys a good balance between theoretical rigor and useful applications. Since we will only use a few sections from it, it is optional but highly recommended, especially if you are serious about RF design. I will make available the sections we use in the class, but you should know the remainder of the book contains a wealth of useful information.

4. Supplementary references: many will be made available in the lab through the entire quarter; these will also be discussed in lecture but otherwise not listed here. You should foster an “I’m curious” approach and independently look over them on your own.

5. Many lecture notes and handouts given throughout the quarter, along with component datasheets and any related application's notes, typically in pdf form; these will also be posted on our class website.

Homework:

Homework will be assigned and collected *during* class sessions. (They may or may not be posted on our website.) To receive full credit, your work must be well organized, literately readable and show evidence of thoughtful attention to each problem. Since many questions will require written discussions, I expect college level writing. First-draft exposition will be considered deficient and graded accordingly. Math-only problems require a restatement of the problem along with brief orienting discussions about the math you will be presenting and interspersed for cohesion internally; convince me that you know and understand what you are doing.

Grading will follow as described below.

A: An "A" grade means *excellent work*, reflecting complete and thoughtful solutions. Numerical correctness is not the sole criterion, conceptual correctness is also very important. Engineering design problems in particular require a clear exposition of the concepts involved.

B: A "B" grades means *very good work*. It typically reflects thoughtful solutions displaying clear evidence of attention to each problem but with conceptual vagueness or unexplained use of math formulae or models. I assign this grade for well-done but partially understood work.

C: A "C" grade means minimally *satisfactory work*. Numerically correct results without evidence of conceptual understanding or thoughtful solution warrant this grade. I will give this grade to answers consisting of mathematical presentations without appropriate preface or orienting discussion. I will also give this grade to poorly organized, difficult to follow, "dash-it-off", non college-level writing. Both of these are typical of assignments done at the last minute (the "exponential-push" strategy).

D: Incomplete problem sets.

… to each of the above, **+** or **-** as appropriate…

Laboratory:

Details about laboratory work, including the basic project assignment, engineering notebooks and reporting, will be handed out and fully discussed during the first scheduled lab session. Note that you must keep a proper chronologically ordered *engineering notebook* that will be used in conjunction with your actual hardware to assess progress and assign grades.

Please note that unlimited and unsupervised use of laboratory equipment (computers, printers etc.) and resources (web-access, email, ftp etc.) is a *privilege*, not a right. Any abuse of equipment or misuse of resources will result in the immediate loss of these privileges, and may result in disciplinary action by the University. Note too that all food and beverages are expressly prohibited in lab, and the door should never be left propped open. We enjoy competent and professional support from the Baskin Engineering Lab Support Group (bels@soe.ucsc.edu). Immediately report any problems pertaining to the laboratory to them; they can also be consulted for parts you may need.

Evaluation:
Since the lecture and laboratory are very closely related, you must pass both of them to obtain credit for the course. If you fail either one, that grade will be assigned to both sections.

1. Lecture:
   Homework ………. 30%
   Midterm …………. 35%
   Final Exam ……….35%

2. Laboratory:
   See separate lab course assignment sheet issued during the first laboratory.

Academic Integrity:
The student-instructor relationship is based on imputed trust. Violations of this trust by deceptively offering the work of others as your own, cheating on examinations etc. will result in formal charges of academic dishonesty being brought against you.

Students who qualify for DRC accommodations need to submit appropriate paperwork early in the quarter.