Ph/EE 118A – Fall 2009
Principles of Measurement
Tu, Th 2:30-3:55pm / Downs 103
Make-up Lecture Times: *t.b.d*

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Class URL: http://www.its.caltech.edu/~ph118/

— *COURSE INFO* —

This course will provide a coherent introduction to ultralow noise electrical measurements, both dc and ac, that are crucial to experimental research. This is stuff that I want all of my students to know. Topics surveyed include physical noise processes, signal transduction, models of small signal amplification, as well as modulation, detection, synchronous and lock-in detection, signal sampling techniques, digitization, signal transforms and electronic correlations. Where possible, examples will be formulated around current approaches providing state-of-the-art sensitivity.

1. Prerequisites

This is a class for those embarking upon a career involving laboratory measurements. It is primarily designed for beginning graduate students or postdocs in the physical and engineering sciences. Undergraduates involved in laboratory research may, with written permission from their laboratory advisor, take this course. The official prerequisites are Analog Electronics (*e.g.* Ph105) and Statistical Mechanics (*e.g.* APh105 or Ph127) … but I'll say unofficially there are *none* but the desire to learn. But in my lectures I'll assume you're familiar with basic circuit theory and electronics, as well as Fourier analysis, auto- and cross-correlations, and concepts like spectral densities, etc. You'll probably find it a hard go without knowledge of these. Additionally, the class will make a whole lot more sense to you, and of will be of obvious relevance, if you've already had some exposure to laboratory research involving electronic measurements.

2. Textbooks & Reading Materials.

I will assign readings from a wide variety of materials; there is simply not a good sole source. You do not necessarily need to purchase these books, as they will be on reserve (in my assistant Su's office for 1 day check-outs, if not at the library). But these can be found used very cheaply only, and they are useful references for an experimentalist to have on hand.

(a) **"H&H"** = ***The Art of Electronics***, **2nd Edition**, Paul Horowitz & Winfield Hill, Cambridge University Press (1989) – (you can find this used on Amazon for <$50.) My lectures will not follow the book, but I will definitely assign reading from it. In the long run, I think you'll find this a very useful book to have although the parts lists are dated. ISBN 0 5213 7095 7

(b) **"Malmstadt"** = ***Electronics and Instrumentation for Scientists***, Howard V. Malmstadt, Christie G. Enke, & Stanley R. Crouch, Benjamin/Cummings, 1981. This is out of print, but you can get a used copy on Amazon real cheap (sometimes for less than $10. Don't pay premium price for it!) ISBN 0 8053 6917 1

(c) **"Morris"** = ***Measurement Instruments & Principles,* 3rd Edition,** Alan S. Morris, Elsevier, Amsterdam, (2001). Another book that you'll be able to find used very cheaply. I will be assigning some readying from it. ISBN 0 7506 5081 8

(d) **"Handout"** = Finally – there's lots of reading material on the website, and some of it will constitute your assigned weekly readings.

4. Reserve Books at Library

(a) ***Low noise electronic system design***, C.D. Motchenbacher & J.A. Connelly, New York: Wiley, 1993. TK7867 .M69 (1993)

(b) ***Noise Reduction Techniques in Electronic Systems, 2nd ed.***, H. W. Ott, New York: Wiley, 1988. TK7867.5 .O87 (1976)

5. "General Philosophy", Grading, Exams, and Expectations (mine).

This class, held in more of a "seminar" format, is intended as a resource to help build your knowledge base for current and future laboratory investigations. So, in the long run, your grade is really the least important element of the class. Auditing, assuming it is accompanied by enthusiastic participation, is whole-heartedly encouraged. *But* since many of you will be taking the class for credit, there must be some ground rules. Here are the gory details…

For those taking the class for credit:

- I offer only P/F grading. No exceptions (please don't ask.)
- Readings will be assigned, and will form essential part of the course learning along with the homework
- Questions of me will be strongly encouraged, and I will ask questions of each of you in class. Be prepared; do the reading beforehand.
- I *expect* your participation in class; you will not pass if you do not attend the lectures and actively participate in class. Reason being… there isn't a book that you can "cram" from to learn this stuff at the last minute in the privacy of your room. Furthermore, it is not likely you'll have sufficient understanding of the material to pass the exams without attending class, keeping up with the readings, reviewing the class notes, and doing the homework examples. (Please be forewarned!)
- If you will not be able to attend a lecture you should send me and the T.A. an e-mail beforehand. If you find you have to miss more than two lectures, please consider taking the class another year.
- There may be both mid-term and final exams; these may either be take-home or in-class.

6. Homework… will be assigned on roughly a weekly basis. At the completion of each lecture the TA will post a list of key concepts that you should strive to understand… mid-term and final exam questions will most likely be found amongst these topics.

7. Web Site. I will post lecture notes, reading material, and supplementary information on the Ph118 web site. You'll need the password (given in class) to access my materials. For economy of size these documents will be encoded in .pdf format. You'll need Adobe Acrobat to read the .pdf files. The reader can be downloaded free at: http://www.adobe.com/prodindex/acrobat/readstep.html

8. (Approximate) Syllabus. As follows… (but there are *always* minor adjustments and optimization in mid-stream):

Lec.	*Date*	*Principal Topics*	*Key Concepts*	*Reading Materials*
-	Tue 29 Sep	**Sign up / no lecture**		
1	Thu 1 Oct	Signals *vs.* Noise	Signal characteristics *vs.* noise; signal-to-noise ratio; signal domains, transduction, responsivity & backaction.	*Check web.*
2	Tue 6 Oct	Measurements & Measurement System Architecture	General measurement requirements & strategies; metrics for & schemes to optimize signal-to-noise ratio; generic measurement system architectures & analyses.	*Check web.*
3	Thu 8 Oct	Review of Fourier Analysis	Fourier series & integrals, power spectral densities, Parseval's theorem, auto- & cross-correlations; Wiener-Khinchine theorem.	*Check web.*
4	Tue 13 Oct	Physics of Noise	Classes of noise processes & physical origins; conceptual generalization & fluctuation-dissipation theorem, practical consequences, characterization & modeling of noise.	*Check web.*
5	Thu 15 Oct	Signals & Noise in Low-frequency Amplifiers	Low-*f* amplfier classes, attributes & performance metrics; practical realizations, and important specifications and realms of applicability.	*Check web.*
6	Thu 20 Oct	Low-*f* Amplification	Equivalent noisy circuit models for amplifiers, and their consequences in the analysis of noise in measurement systems; evaluation of cascaded systems.	*Check web.*
7	Thu 22 Oct	Transformers, and the transformation of R_{opt}	Ideal transformer limit, practical limitations, physical realizations.	*Check web.*
8	Tue 27 Oct	Alternative signal transformations	Resonant impedance transformations; parallel devices; correlation techniques; ideal transformation limits & practical limitations, physical realizations,	*Check web.*
9	Thu 29 Oct	Circuit Modeling and Evaluation	Phasors and rotating frame transformations, Nyquist plots, Bode plots, Introduction to circuit modeling	*Check web.*
	t.b.d.	**Midterm examination**		

Lec.	*Date*	*Principal Topics*	*Key Concepts*	*Reading Materials*
10	Tue 3 Nov	Nonlinearity and Signal Distortion in Amplifiers	Origin of nonlinearity and its characterization, harmonic and intermodulation distortion.	*Check web.*
11	Thu 5 Nov	Noinlinearity Revisited: Modulation and Frequency Conversion, I	Theory of modulation and mixing, practical realizations, important component specifications	*Check web.*
12	Tue 10 Nov	Modulation and Frequency Conversion, II	Device performance metrics, Theory of noise in frequency conversion devices	*Check web.*
13	Thu 12 Nov	Filters in the Time & Frequency Domain, I	Filter types, characterization, and specifications; practical low and high frequency realizations.	*Check web.*
14	Tue 17 Nov	Filters in the Time & Frequency Domain, II	Filter types, characterization, and specifications; practical low and high frequency realizations.	*Check web.*
15	Thu 19 Nov	Synchronous Detection I	Lock-in detection, typical system architecture	*Check web.*
16	Tue 24 Nov	Synchronous Detection II	Chopper-stabilized amplifiers, Theoretical *vs.* realizable lock-in performance	*Check web.*
-	Thu 26 Nov	**No Class** – *Thanksgiving Break*		
17	Tue 1 Dec	Synchronous Detection III	Optimal signal capture, derivative measusrement, multiple frequency techniques; examples.	*Check web.*
18	Thu 3 Dec	Bridges & Nulling	Modeling and analysis of dc and ac bridges in ideal limit, practical limits to ideal performance	*Check web.*
	t.b.d.	**Final examination**		