Ph/EE/BE/APh 118a – Winter 2021	**Prof.:**	Michael Roukes *(roukes@caltech.edu)*
Physics of Measurement	**T.A.s:**	Honglie Ning *(hning@caltech.edu)*
Tu, Th 2:30-3:55pm PT – online via zoom		Bohan Li, *(bli2@caltech.edu)*
Class URL: http://www.its.caltech.edu/~ph118/	**Admin.:**	Nancy Rappard, x2933, 127 Bridge Annex *(nrappard@caltech.edu)*

— *COURSE INFO* —

This course will provide an introduction to the concepts and principles of physical measurements that are crucial to experimental research. This is stuff that I want all of my own research group members to know well. Topics surveyed include signal domains and transduction, responsivity, backaction, physical noise processes, bandwidth and information, nonlinearity, frequency conversion, modulation, synchronous detection, signal-sampling and time-domain methods, digitization, signal transforms, and multiple-measurement correlations. Where possible, discussion will be formulated around current approaches that provide state-of-the-art sensitivity. Possible examples may include quantum interference devices, bio/chemical sensors, photonic devices, and micro- and nanomechanical systems.

1. Prerequisites.

This is a class for those embarking upon careers involving laboratory measurements. It is primarily designed for beginning graduate students in the physical and engineering sciences, however others are welcome. The class will make most sense to you, and be of obvious relevance, if you've already had some exposure to laboratory research involving hands-on physical measurements. Undergraduates *who are involved in laboratory research* may, *with a note of recommendation from their research advisor*, also 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 *no* prerequisistes but the desire to learn and a willingness to ask questions in class. However, 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 some knowledge of these. Class topics will be discussed from the context of solid state physics; previous coursework in this are will be helpful. With sufficient interest, the TA may schedule a tutorial or two on such background topics.

2. Required Textbooks

None – but there will be lots of good stuff for your perusal on the class web site. I strongly recommend you purchase Horowitz & Hill, if you don't already have it (see below). I will provide you with pdfs for all of the required reading this year.

3. Reserve Books

"The Art of Electronics", 3rd Edition, Paul Horowitz & Winfield Hill, TK7815 .H67 (2015)
"Low Noise Electronic System Design", C.D. Motchenbacher & J.A. Connelly, TK7867 .M69 (1993)

4. “General Philosophy”, Grading, Exams, and Expectations (mine)

This class, held in somewhat of a “seminar” format, is intended as a resource to help build your knowledge base for current and future laboratory investigations. Hence, your grade is really the least important element of the class.

- **For undergrads, Ph118a is offered only for a letter grade**. (Graduate students may opt for P/F grading.) Final grades will be based on student performance in the following areas: 30% class participation, 30% homework, 30% final exam. Grading for Ph118b/c is usually P/F for all.
- Class participation from students is mandatory; so **come prepared** and **be forewarned** – following the Socratic method, I will often ask unsolicited questions of each of you in class!
- Readings will be assigned and form essential part of the course learning along with the homework sets.
- I ***expect*** your participation; and **you will not pass this course if you do not attend all the lectures** (this is a seminar-like class) **and if do not actively participate in class.** 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, and reviewing the class notes. We are going to have to adapt this Winter ’21, as it will be the first time I try this with live lectures online.
- Depending upon inchoate factors there could be both mid-term and final exams.

6. Homework… will be assigned on a weekly basis. Mid-term and final exam questions will most likely be similar to homework 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 these 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. Lecture Times. Lectures will be held on Tuesdays and Thursday from 2:30-3:55pm. The calendar on p. 5 shows the days of the class lectures for the Fall term. If we need to make up a class, the make-up lecture will be held on Friday.

9. (Approximate) Syllabus. As follows… (but be prepared for minor adjustments and optimization in mid-stream).

Lec.	***Date***	***Principal Topics***	***Key Concepts***	***Reading Materials***
1	Tu 5 Jan	**Class Organization** *–and-* **Coupling, Responsivity, Noise, and Backaction**	Signals *vs.* Noise. Perturbation of measurand by measurement. Information, and its transformation in a measurement system.	Readings on web
2	Th 7 Jan	**Canonical Approaches to Measurements; Signal Transduction; Spectral Density**	Deflection, difference, & nulling methods; their applications & trade-offs. Signal transduction & resolution. Spectral Density.	Readings on web
3	Tu 12 Jan	**System Dynamic Range; Physics of Noise, I**	Importance of *system* dynamic range & its estimation. Equilibrium vs. non-equibrium noise, and microscopic physical mechanisms.	Readings on web
4	Th 14 Jan	**Physics of Noise, II**	Equilibrium vs. non-equibrium noise, and microscopic physical mechanisms.	Readings on web
5	Tu 19 Jan	**Modeling Noise in Measurement Systems, I**	Important nuances of amplification: amplifier methods & classes, their attributes, specifications, and generic applications	Readings Horowitz & Hill
6	Th 21 Jan	**Modeling Noise in Measurement Systems, II**	Equivalent models for noisy circuits and consequences, practical realizations.	Motchenbacher & Connolly
7	Tu 26 Jan	**Transformations to Optimize Signal-to-Noise Ratio (SNR)**	Ideal signal transformations, practical limitations, physical realizations	Readings on web
8	Th 28 Jan	**Resonant Systems, Parallel Devices, and Impedance Transformations**	Ideal limits, practical limitations, physical realizations, shielding; uncorrelated noise sources *vs.* signal correlations	On web
9	Tu 2 Feb	**Cross-correlation-based measurements**	Auto- and cross-correlations, cross spectral densities, correlated v. uncorrelated signal & noise analysis; practical implementation	On web
10	Th 4 Feb	**Signal Sources, Spectral Purity, Phase Noise**	Signal generation, spectral characterization, Phase noise, Allan Deviation.	On web

Lec.	*Date*	*Principal Topics*	*Key Concepts*	*Reading Materials*
11	Tu 9 Feb	**Nonlinearity and Signal Distortion, I**	Origin of nonlinearity and its characterization.	Hardy
12	Th 11 Feb	**Nonlinearity and Signal Distortion, II** **Modulation, I**	Harmonic and intermodulation distortion and its effects in measurements.	On web
13	Tu 16 Feb	**Modulation, II; Frequency Conversion I**	Examples of c-c measurements; evaluation. Theory of modulation and mixing, practical realizations, important component specs.	On web
14	Th 18 Feb	**Frequency Conversion, II**	Examples of c-c measurements; evaluation. Theory of modulation and mixing, practical realizations, important component specs.	On web
15	Tu 23 Feb	**AC vs. DC measurements;** **Synchronous Detection I**	When does averaging help/hurt? When to employ AC vs. DC measurements; Synchronous detection, typical system architecture	On web
16	Th 25 Feb	**Synchronous Detection, II**	Optimal signal capture, derivative measurement, practical limits to ideal performance.	On web
17	Tu 2 Mar	**Bridges & Nulling**	Architectures for precision measurements.	On web
18	Th 4 Mar	**Bridges & Nulling, II**	Architectures for precision measurements, cont'd.	On web
19	Tu 9 Mar	**Measurement Examples**	Applications of the formalism.	On web

Winter 2021 – Lecture Calendar for Ph/EE/BE/APh 118a

January

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

February

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28						

March

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Lecture
Holiday
NO LECTURE