Applied Physics 190c: Quantum Electronics

(Dated: Spring, 2016-17)

Instructor:
Oskar Painter
Office: Rm. 266, Watson Bldg., x8008
Office Hours: by appointment
e-mail: opainter@caltech.edu

Lectures:
TuTh 10:30-11:55AM, Rm. 104 Watson.

Recitation Sessions and Make-up Lectures (as needed):
We 6:00-7:25PM, Rm. 104 Watson.

Teaching Assistants:
Mahmoud Kalaee (mh.kalaee@gmail.com)
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TA Office Hours: Tu and Th, 4-6PM (or by appointment), Watson 268.

Course Website:
http://copilot.caltech.edu/classes/aph190

Course work:
$\sim$ 6 HWs. HW will be given out during Thursday's class, and due the following Friday evening. HWs should be handed in to the "INBOX" box outside Watson 266/264. You can pick up graded HWs and exams from the "OUTBOX". There will be a final exam. With regard to grading, HW will make up 80% of your grade, and the final exam 20%.

Policies:
Homework: Limited collaboration allowed; make sure to work out the details of solutions on your own. Use of any texts, any notes, computers, etc. is fine. For MATLAB and Mathematica output please provide brief (but comprehensible) commentary.

Textbooks and References:
Recommended Texts and Papers:
"Introduction to quantum noise, measurement, and amplification," by Aash Clerk, et al. [1].
"Quantum Noise," by C. W. Gardiner and P. Zoller [2].
"Methods in Theoretical Quantum Optics," by Stephen M. Barnett and Paul M. Radmore [3].
"Statistical Methods in Quantum Optics 1: Master Equations and Fokker-Planck Equations," by Howard J. Carmichael [4].
"A Computation Toolbox for Quantum and Atomic Optics," by Sze M. Tan.

Recommended for supplemental reading:
"Optical Coherence and Quantum Optics," by L. Mandel E. Wolf[5].
"Optical Resonance and Two-Level Atoms," by L. Allen and J.H. Eberly[6].
"Quantum Optics," by Marlon O. Scully and M. Suhail Zubairy[7].

Course Outline: APh190c will cover several topics of particular relevance to current research in quantum optics and quantum electronics: (i) quantum noise and standard quantum limits in weak measurements, (ii) quantum-limited amplifiers, and (iii) cavity- and waveguide-QED systems. Below I give a week-by-week breakdown of what we will cover in class.

1. **Week 1 (4.4 and 4.7): away**
2. **Week 2 (4.11 and 4.13): course overview and basics of classical and quantum noise**
   course overview; notes on notation; input/output formalism; quantum noise of a cavity coupled to a thermal radiation bath;
3. **Week 3 (4.18, 4.19 (make-up #1), 4.20): homodyne/heterodyne detection**
   ideal homodyne/heterodyne detection; experimental realization; calibrating the noise in an optical homodyne detector;

4. **Week 4 (4.25, 4.24 (make-up #2), 4.27): continuos position measurement of a mechanical object**
   intro to cavity optomechanics; derivation of the standard quantum limit (SQL) in position measurements; special topic: group theory of optomechanical crystals

5. **Week 5 (5.2 and 5.4): general linear response theory**
   quantum constraints on noise; evading the detector noise inequality; quantum non-demolition measurement (QND) detection of a qubit

6. **Week 6 (5.9 and 5.11): linear amplifiers**
   SQL of linear amplifiers; the non-degenerate parametric amplifier

7. **Week 7 (5.16 and 5.18): intro to cavity-QED and circuit-QED**

8. **Week 8 (5.23 and 5.25): intro to waveguide-QED**

9. **Week 9 (5.30 and 6.1): waveguide-QED, cont.**

10. **Week 10 (6.5 through 6.9): final exam period**
    6.1-6.8 = study. Pick up final exam morning of 6.8 from outside of Watson 264, 3 hour time limit to write exam (in blue book), must be handed in by 5pm 6.8 to box outside of Watson 264.

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[1] A. A. Clerk, M. H. Devoret, S. M. Girvin, F. Marquardt, and R. J. Schoelkopf, arXiv:0810.4729 (2010).
[2] C. W. Gardner and P. Zoller, *Quantum Noise* (Springer-Verlag, New York, NY, 1992), 3rd ed.
[3] S. M. Barnett and P. M. Radmore, *Methods in Theoretical Quantum Optics*, Oxford Series in Optical Imaging and Sciences (Oxford University Press Inc., New York, NY, 1997).
[4] H. J. Carmichael, *Statistical Methods in Quantum Optics 1: Master Equations and Focker-Planck Equations*, Texts and Monographs in Physics (Springer-Verlag, New York, NY, 1999).
[5] L. Mandel and E. Wolf, *Optical coherence and quantum optics* (Cambridge University Press, New York, NY, 1995).
[6] L. Allen and J. Eberly, *Optical Resonance and Two-Level Atoms* (Dover Publications, Inc., Mineola, NY, 1987).
[7] M. O. Scully and M. S. Zubairy, *Quantum Optics* (Cambridge University Press, Cambridge, United Kingdom, 1997).