Course Information and Syllabus – Fall 2024
6.237 - Modern Optics Project Laboratory
6.637 Optical Imaging Devices and Systems

1. Overview
Most 2-D and 3-D optical imaging systems involve the use of one or more of the following: **light sources** (e.g., lasers, light-emitting diodes, lamps), **spatial light emissive or modulation components** (e.g., OLED, liquid crystal, electro-optic-crystal, MEMS light modulators), **photodetector arrays** (e.g., photodiodes, CCDs), **information storage devices** (e.g., optical disk, photorefractive material), **image processing subsystems** (e.g., spatial filtering components, color filtering components, lenses, gratings, digital signal processing systems), and of course, the human eye.

This joint offering of 6.237 and 6.637 starts with a focus on the fundamental principles of optics and optical phenomena, and includes a laboratory focus on imaging devices and systems. The course has significant design activity, so mastery of the fundamentals is essential. The topics covered include: the polarization properties of light, reflection and refraction, coherence and interference, Fresnel and Fraunhofer diffraction, Fourier optics; incoherent and coherent 2-D imaging systems; image resolution; optics of the eye; principles of 3-D imaging systems (near eye and projection); static and dynamic holographic imaging systems (including photorefractive systems); electro-optic, liquid-crystal spatial light modulation; 2-D emissive displays such as OLEDs; lasers, principles of image detectors for the visible and infrared; 2-D and 3-D optical image storage technologies; adaptive optical imaging systems.

Lectures are supplemented with weekly laboratory exercises and 7 problem sets. The course concludes with a final project of the student's choosing. The 6.237 students must do an experimental project.

1.1 Additional Requirements for 6.6370
The 6.6370 students are encouraged (not required) to do the labs in collaboration with the undergraduates. Much is lost if the 6.637 students do not avail themselves of this opportunity. The 6.637 students have additional homework problems and quiz problems beyond the core problems required for 6.237. For their project, the 6.637 students may do any combination of theoretical, experimental, simulation work that is approved by the instructor.

Prerequisites: The prerequisite is 6.300. Exceptions can be made by the Lecturer.
Lecture: Room 34-304, TR 1:00 - 2:30pm
Laboratory: Optics Lab: 38-633, Time TBA.
Optics Lab Phone: x3-4619 (Note: we share the lab phone with other classes on the floor).

Course Staff

Lecturer: Prof. Cardinal Warde Room 13-3102 Extension 3-6858 warde@mit.edu	**Teaching Assistant**:
Writing Program Coordinator: Juergen Schoenstein Room E18-240A juergen@mit.edu	**Course Secretary**: TBD

Course Websites: http://web.mit.edu/6.161

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them" - Sir William Bragg

2. Course Components for 6.237 & 6.637

The primary course components are Lectures, in-class demonstrations, homework, quizzes and a final research project. The Laboratory exercises of 6.237 are optional for the 6.637 students.

2.1 Homework Problems for 6.237 & 6.637

The homework often teaches how to apply the material covered in class to real-world problems, and hence it determines a significant percentage of the grade. One homework problem set will be handed out each week for the first 7 weeks of the term. The homework problems are designed to encourage outside reading, and to strengthen your grasp of the fundamentals. How you got to your answer is very important. Show your work! The grader will deduct points for answers which lack justification.

Your problem sets may be handed in as a hard copy at class on the due date, or electronically as a PDF file by 11:59 pm on the due date via e-mail addressed to warde.csf@gmail.com with a copy to the TA. Problem sets will not be accepted after the solutions are handed out. Points will be deducted for late problem sets.

2.2 Laboratory Exercises for 6.237

There are six laboratory exercises concerned with the observation and measurement of basic optical and imaging phenomena. Each laboratory exercise consists of pre-lab exercises (to be completed before entering the lab) and several experimental components dealing with the same theme, designed to complement the lecture material. The course staff will set up each laboratory exercise for one week only, and you must complete each laboratory exercise sometime during the week that it is set up. Some of the laboratory exercises require a considerable amount of setup time, and once taken apart, will not be set up again. There are two additional laboratory exercises that will be done as in-class demos.

To make the laboratory exercises flow smoothly, please arrive on time for your assigned lab sessions. Additionally, please come prepared: this means that you will have: (1) read the lab handout before arriving, (2) completed the pre-lab, and (3) brought your questions with you. As part of the pre-lab, you must find and review the material necessary to complete the lab before you begin. To ensure that you will have all the data you need for your write-ups, you will be required to take notes in a laboratory notebook. More information as to laboratory write-up specifics will become available during the first week of the term.

For all labs, write your answers in your lab notebook, and be prepared to discuss them in your oral presentations to the TA and the CIM coordinator. Be sure to include derivations, solutions, graphs, diagrams, data, and physical explanation when answering the lab questions. Also be sure to include copies of any computer print-outs. Your notebooks may be checked at any time by the TA or professor to make sure they contain all necessary information. A well-kept notebook will help ensure that you not fail to gather all the necessary data for your write-up (as you may not be able to come back and retrieve the data before the apparatus for a given laboratory exercise has been dismantled).

For the even-numbered laboratory exercises (2, 4 and 6) the laboratory report will be in oral form. The same amount of care and preparation must go into these oral reports as if the reports were written. For each of these oral reports, each student will prepare a 10-minute Power-Point presentation that addresses all of the topics that would have been covered in a fully written report. These oral reports will be scheduled by appointment with the writing coordinator and TA and they must be completed within one week after the laboratory work is done.

The written laboratory exercise reports for the odd-numbered exercises (3, 5 and 7) must be turned in to the Teaching Assistant (TA) one week after the exercise was scheduled. In the event the report is due on a day when the Institute is closed, the report should be turned in to the TA by 5:00 pm on the first day that classes resume even if the Laboratory is not open on that day. This may be a day when 6.237 does not meet. Late laboratory exercise reports should be handed directly to the TA.

2.3. CI-M Requirement for 6.237

There are four assignments for which write-ups are required: Laboratory exercise Nos. 1A & 1B (geometric optics), Laboratory exercise No. 3 (coherence and interferometry), Laboratory Exercise No. 5 (holography), and the final project report. All other Laboratory Exercises (2, 4, and 6) will be presented orally before the MOL staff and a staff member from the Writing, Rhetoric & Professional Communications (WRAP) Program. The written laboratory exercise reports should be limited to a maximum of 15 single-spaced pages with fonts no smaller than 10 point. The final project report should not exceed 30 pages with fonts no smaller than 10 point.

You will meet with your WRAP instructor several times throughout the semester: There will be opportunities to get feedback and practice for all oral presentations; in addition, there will be four mini-tutorials (each about 30 minutes long) to introduce you to technical communication, and to writing reports on technical research.

Laboratory report No. 3 will be graded for its technical merit by the MOL staff, and by staff from the WRAP Program who will read it for its communication effectiveness and provide feedback to you. A grade for the writing component of this report will be assigned after your final revision. You can do as many revisions as you wish so as to practice your writing skills, essentially without penalty.

Laboratory exercise No. 5 will be graded by both the MOL staff (for technical content) and the Writing Program staff (for communication effectiveness) and feedback will be given. Your Lab 5 report must then be revised and resubmitted to the Writing Program. The Writing Program staff will assign a final grade based on the revised report.

The end-of-term final project report will also be graded for its clarity and completeness, but there will be no opportunity to rewrite the final project report. Further, all students must give an oral presentation on their end-of-term final project on the last day of the class. This oral presentation will be graded for its communication effectiveness, as part of the final project report grade. The communication intensive portion of this subject counts for about 20% of the overall grade (see grade distribution table below).

2.4 Quizzes for 6.237 & 6.637

The quizzes will be given during the regular class period (see class calendar). These quizzes will cover broad ideas, as presented in lecture, lab, and homework. The quizzes will consist of short questions intended to test your knowledge of basic optical principles, imaging and laboratory optics. These quizzes will be open book (Prof. Warde's class notes). If you have done the reading, attended the lecture, completed the homework, and carried out the labs, you should be well prepared for the quizzes. These quizzes will enable the teaching staff to diagnose both their teaching and your comprehension.

2.5 Final Research Project and Oral Presentation for 6.237 & 6.637

2.5.1 The Project proposal

In preparation for the final project, each student or team of students will submit a one-page design **Project Proposal** in week 7 that presents an accurate and compelling account of a contemplated project. At this stage, the objective is not to "sell" an incomplete design, but rather to elicit the most useful feedback possible from your audience of experts (Instructor, TA, or another expert). To do so, the student/team should present evidence of the significance of the problem, of the merit of the proposed solution to that problem, and of the novelty of the solution. For 6.237 the projects must be experimental in nature. For 6.637, the project may be experimental or theoretical, or simulation based, and project proposals that include an in-depth investigation or review of an optics, or imaging topic not covered in class are acceptable.

To make all the final projects roughly equal in difficulty and time requirement, we have provided below several possible final projects (which will still allow for, and require, innovation). Additionally, we will allow students to start the final project as soon as they wish, hopefully reducing end-of-the-term stress. We will provide all the necessary lab equipment and all the technical help we can to ensure that your experience is both educational and rewarding. Of course, if you still want to find your own project, or have a hankering to do something different, just tell us and we will try to accommodate you (in such a case, we encourage you to look around MIT for groups that may have projects that interest you). Often, final projects found outside of class turn into RAships and M.Eng. theses.

2.5.2 Project Report and Oral Presentation for 6.237 & 6.637

Students may work alone or in a team of two on the research project. At the end of the research project the student/team will: (1) prepare a written research report (30-page limit) and (2) make an oral conference-style 10-minute in-class presentation. The goal of the oral presentation is to teach your newly acquired knowledge to the class. The oral presentation must include a discussion of the relevance or the potential impact of the technology on society. The presentations will be graded on: (a) the clarity of the presentation, (b) the substance of the material presented, and (c) the creativity/innovation in showing or speculating on the impact or application (present or future) of the technology.

Areas that may be considered for research projects include:

- Challenges in near-eye display technology
- Flat panel display technologies
- Real-time holographic displays
- Electronic imaging systems
- Thermal imaging systems
- 2-D and 3-D optical storage technologies
- Optoelectronic networks and processors
- Optical neural networks
- Adaptive optical systems
- Coherence tomography
- Recent Advances in Microscopy
- Waveguide displays
- 3-D Volumetric imaging
- Near real-time FT holography in a photorefractive crystal
- Use of a cell phone as a SLM

2.6 Writing the Final Project Report for 6.237 & 6.637

The final project report should not exceed 30 pages in length and should be written in accordance with the outline followed by most professional journals in the field (e.g., Applied Optics or Journal of the Optical Society of America, IEEE journals, etc). Alternatively, you may use the outline provided below.

1. A cover page which states the title of experiment, your name, subject number, the date, and the name of the person who supervised your work.
2. A one-paragraph **Abstract** that states the problem being addressed or the goals of the research, the procedures used to solve or analyze the problem, and the salient findings, conclusions or implications of the work.
3. An **Introduction** that contains a brief description of the problem being investigated as well as brief background information to familiarize the reader with the significance or importance of the work to the field. Be sure to define all uncommon terms.
4. A section describing the **Approach** used. This section should briefly describe the general techniques or methods used to explore the phenomena being investigated. It may, therefore, include a brief theoretical formulation or modeling of the problem. For brevity, you should cover the principles at a level such that one with a similar educational background (MIT junior or senior) can follow your reasoning. Do not re-derive complicated equations. Instead you should state the equation, cite the reference (see 8 below) where one can find the derivation, but interpret each term in the equation so the reader can understand the physical concepts involved.

5. A brief description of the apparatus used, followed by your **Experimental Procedure**. Use as many diagrams as you need to describe the apparatus and its operating principles, and how the data were taken.
6. A section describing your **Experimental Results and Analysis**. Present raw data, whenever possible, in tabular form, and derived results or analysis, whenever possible, in graphical form.
7. A section summarizing your **Conclusions** with comments on the errors in your measurements, and recommendations for improving the measurements or the experiment. Your conclusions should also tie in to the stated objectives of the experiment so that the reader gets your opinion of the overall success of the work. This is also a good place to speculate on the potential applications of your work.
8. A list of **References** that support claims made in your report.

Should you still be in doubt, use the bold-face words above as section headings in your reports.

3. Grading Rubric

3.1 Grading Rubric for 6.237

The laboratory exercises (described below) are an integral part of 6.237, constitute a majority of your learning, and thus the final grade. Homework problem sets also make up a significant portion of the final grade. The two quizzes are obviously important since they represent 20% of the grade. Your performance on the Final Project is also a very important portion of the evaluation of your overall performance. The approximate percentage values are as follows:

- 30 % labs (includes active participation in lab, performance on pre-lab, good laboratory notes, and the communication component)
- 20% Homework
- 20% for the in-class Quizzes,
- 30% Final Project (including the communication component)

3.1.1 CIM Laboratory Grading Details for 6.237

The table below summarizes the lab grading algorithm. We will take into account participation in the classroom and in the laboratory as well as attendance when deciding borderline final grades.

<table>
<tr><th rowspan="2">Assignment</th><th colspan="5">% of Grade</th></tr>
<tr><td colspan="2">Technical</td><td colspan="2">CIM Written</td><td>CIM Oral</td></tr>
<tr><td>Lab 0 (Safety)</td><td colspan="2">0</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Lab 1</td><td colspan="2">3</td><td colspan="2">1</td><td>0</td></tr>
<tr><td>Lab 2</td><td colspan="2">3</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>Lab 3</td><td colspan="2">3</td><td colspan="2">1</td><td>0</td></tr>
<tr><td>Lab 4</td><td colspan="2">3</td><td colspan="2">0</td><td>2</td></tr>
<tr><td>Lab 5</td><td>3</td><td>3</td><td>1</td><td>2</td><td>0</td></tr>
<tr><td>Lab 6</td><td colspan="2">3</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>Homework</td><td colspan="2">20</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Quizzes</td><td colspan="2">20</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Final Project</td><td colspan="2">22</td><td colspan="2">5</td><td>3</td></tr>
<tr><td>Total</td><td colspan="2">83</td><td colspan="2">10</td><td>7</td></tr>
</table>

Please note: To earn a passing grade (A, B, C) in this subject, you must complete and either write up or present each of the six laboratory exercises within the prescribed time period. Thus, at the end of the term no grade of Incomplete will be given if you have incomplete lab reports! Also, since most students do well on both the labs and the Final Project, performance on both the problems sets and quizzes become an extremely important factor in determining the final grades.

Note from the TA: Please do not become discouraged if your score on the first lab seems low. Lab 1, while it does count as part of the final grade, should be viewed as a steppingstone into the course. Just do the best you can on this Lab. Assume nothing and be very thorough in your explanations! Do not assume that the TA knows how you arrived at your answers. Assume the TA has never taken this class, and thus needs a full and detailed explanation. While you may have the correct answer, how you got there is more important! **You will not receive credit for answers without explanation.** For all labs, the TA will only grade your submission if you had shown up at the lab session and actively participated in the lab experiments.

3.2 Grading Rubric for 6.637

6.637 quizzes have additional quiz and homework problems beyond the core problems for the 6.237 students. The grade distribution is as follows:

- 35% Homework
- 40% Quizzes (20% each)
- 25% Research project

4. General Logistics (6.237 & 6.637)

4.1 Neatness and Clarity

To ensure that you get the maximum number of points on each Lab and homework assignment, make sure to be neat! The TA/grader will not grade messy work. Additionally, messy work will delay turnaround on both problem sets and homework. Questions on both problem sets and labs must be answered clearly and succinctly. The TA/grader will be looking for demonstrated understanding. It is preferred that you explain in words when possible; this will ensure that you get the maximum number of points for your effort. However, do not neglect mathematical rigor. When math is needed, it must have the proper units and be clearly written. The clearer and succinct your answers, the better. However, do not compromise important details. The TA/grader will not accept numerical answers without their derivation. Likewise, the TA/grader will not accept written answers, without appropriate reasoning.

4.2 Labeling and Formatting

Whenever a problem asks for a graph, the student must create a computer-generated graph. All graphs must be labeled and titled - a copy of the graph must be transferred to your lab notebook or your homework problem solution. Use callouts to point out important regions of your graphs. Any written answers exceeding one page must be typed. It is suggested that you format all your answers using LaTeX or a comparable typesetting package.

Label your answers clearly; the TA/grader will not search extensively for an answer. Circle your answers, and underline key portions of your work which directly aid in the creation of the answer. Points may not be given back if an answer is skipped in the grading process because the answer was difficult to find.

4.3 Use of Computation Software

When computer-based problems are presented, please use Matlab, Mathematica, LabView or Maple to do your work. If you feel much more comfortable with other math packages, that is okay, but please put the code in your public directory along with instructions on its execution. Please include any code and graphs you use in your solutions. Often, unless stated, graphical solutions may be used, especially if they show that you really understand the material. To use Matlab, Mathematica or Maple on Athena, type: add matlab, add math, and add maple at the Athena% prompt.

4.4 Late-Work Policy

Having been an undergraduate once, your TA knows that many of you have obligations which inhibit your ability (on rare occasions) to turn in work on time. If such an emergency arises, notify the TA and the professor in charge before the homework is due (if possible). In order to be fair to your classmates, we must still penalize late work (unless the tardiness was due to medical or similarly urgent reasons and you present a Dean's note).

Additionally, an incomplete problem set will not be accepted. We expect you to make an effort on ALL parts of ALL problems. This gives us the chance to see where you are having problems, if any. If you need additional time, ask for it. You will always receive more points for a completed late problem set than an on-time incomplete one (assuming you turn it in before solutions are handed out). If tardiness becomes a chronic problem, it will significantly degrade our final evaluation of your performance.

4.5 Collaboration

Collaboration is encouraged. Talking with peers about problems helps everyone ("*To teach is to learn twice*." – Joseph Joubert). However, blatant copying and other forms of cheating will not be tolerated. Always acknowledge your collaborators. This will not hurt your grade. In fact, it may help. We care that you learn the material. If you learn best from a friend, that is fine with us.

4.6 Plagiarism

While collaboration is encouraged, plagiarism will not be tolerated. Please become familiar with the various forms of plagiarism so that you avoid making embarrassing and perhaps costly mistakes. Here are two MIT websites where you can learn more about plagiarism:
http://web.mit.edu/writing/Citation/plagiarism.html
http://web.mit.edu/academicintegrity/handbook/handbook.pdf

4.7 Office Hours

Group office hours will be conducted virtually each week at Prof. Warde's Zoom office (https://mit.zoom.us/j/3445367866). Office hours will address questions from the laboratory exercises, quizzes, and problem sets. Office hours may also include hands-on demonstrations of applied concepts. While office hours are not mandatory (except to deliver oral presentations of your laboratory exercises) concepts and material are often reviewed that may show up on quizzes, homework and labs. Students are expected to ask questions and come to office hours prepared.

5. Textbooks and Reading Materials

Class notes will be provided on each topic we cover. However, several of the basic concepts are covered in the following textbooks:

1. J. W. Goodman, *Fourier Optics*, 3rd Edition, Roberts & Co., 2005
2. A. Yariv, Optical Electronics in Modern Communications, 5th Edition, Oxford University Press, 1997.
3. B. Saleh and M. Teich, *Fundamentals of Photonics*, Wiley, 1991.
4. E. Hecht, *Optics*, 4th Edition, Addison Wesley, 2002.
5. M. Born and E. Wolf, *Principles of Optics*, 5th, 6th, or 7th Edition, Pergamon Press, 1980.
6. F.A. Jenkins and H.E. White, *Fundamentals of Optics*, 4th Edition, McGraw Hill, 1976.

Purchase of these textbooks is not mandatory. These books are on reserve in the Barker Library - but occasionally disappear during the term (especially when problem sets are due). They are intended for use as reference material.

Portions of the material we will cover can also be found scattered throughout journals and conference proceedings that include:

Journal of the Optical Society of America
Applied Optics
Optics Letters
Journal of Quantum Electronics
Journal of Display Technology
Applied Physics Letters
Optics Communications
Optical Engineering
Proceedings of the SPIE

Occasionally, students will be expected to read and apply material covered in articles selected from these journals.