OPTI 519 Laser Beam Control and Propagation

Course Description:
This course consists of two complementary parts: (1) an introduction to laser beam propagation through random media and (2) an introduction to beam control for laser systems. The first part will teach students how to derive oft-used parameters like the Fried parameter from first principles. At the end of part one, students will be able to analyze scenarios of interest in terms of these parameters. The second part will teach students how to design laser systems that sense and correct for tilt and higher-order aberrations (both internal and external to the system) using techniques like line-of-sight stabilization, tracking, and adaptive optics. At the end of part two, students will be able to predict laser system performance in terms of scaled parameters.

Prerequisites:
OPTI 505R

Location and Times:
Meinel 305, T/TH 3:30 – 4:45 PM
D2L site:

Instructor:
Prof. Mark Spencer
spencerm@arizona.edu
(520) 621-2927
Office hours: I will host office hours for one hour after each lecture or by appointment.

TA:
TBD

Learning Outcomes:
- Understand the fundamentals of laser beam propagation through random media
- Be able to analyze multiple scenarios of interest in terms of derived parameters
- Understand how to design laser systems that sense and correct for aberrations
- Be able to predict laser system performance in terms of scaled parameters

Required Texts:
Part 1: Larry C. Andrews and Ronald L. Phillips, *Laser Beam Propagation Through Random Media*, 2nd ed. (SPIE Press, 2005).

Part 2: Paul H. Merritt and Mark F. Spencer, *Beam Control for Laser Systems*, 2nd ed. (Directed Energy Professional Society, 2018).

Full texts will be available for download on the D2L website.

References:
- Larry C. Andrews and Melissa K. Beason, *An Engineering Approach to Asymptotics and Approximations: With Applications in Optical Wave Propagation and Imaging in Turbulence*

(SPIE Press, 2025).

- Larry C. Andrews and Melissa K. Beason, *Laser Beam Propagation in Random Media: New and Advanced Topics* (SPIE Press, 2023).
- Robert K. Tyson and Benjamin W. Frazier, *Principles of Adaptive Optics*, 5th ed. (CRC Press, 2022).
- Larry C. Andrews, *Field Guide to Atmospheric Optics*, 2nd ed. (SPIE Press, 2019).
- Robert K. Tyson and Benjamin W. Frazier, *Field Guide to Adaptive Optics*, 2nd ed. (SPIE Press, 2012).
- Jason D. Schmidt, *Numerical Simulation of Optical Wave Propagation with Examples in MATLAB*, 1st ed. (SPIE Press, 2010).
- Richard J. Sasiela, *Electromagnetic Wave Propagation in Turbulence, Evaluation and Application of Mellin Transforms*, 2nd ed. (SPIE Press, 2007).
- Larry C. Andrews and Ronald L. Phillips, *Mathematical Techniques for Scientists and Engineers* (SPIE Press, 2003).
- Vladmir P. Lukin and Boris V. Fortes, *Adaptive Beaming and Imaging in the Turbulent Atmosphere* (SPIE Press, 2002).
- Gregory R. Osche, *Optical Detection Theory for Laser Applications* (Wiley, 2002).
- Robert K. Tyson, *Introduction to Adaptive Optics*, (SPIE Press, 2000).
- François Roddier, Adaptive Optics in Astronomy (Cambridge University Press, 1999).
- John W. Hardy, *Adaptive Optics for Astronomical Telescopes* (Oxford University Press, 1998).
- Michael C. Roggemann and Byron M. Welsh, *Imaging Through Turbulence* (CRC Press, 1996).
- John M. Geary, *Introduction to Wavefront Sensors* (SPIE Press, 1995).
- John W. Strobehn (editor), *Laser Beam Propagation in the Atmosphere* (Springer-Verlag, 1978).
- Akira Ishimaru, *Wave Propagation and Scattering in Random Media* (Academic Press, 1978).

Schedule:

Week 1

1. Course introduction and optics fundamentals for beam control (M&S ch. 2)
2. Random processes and fields 1 (A&P ch. 2)

HW 1 assigned

Week 2

3. Random processes and fields 2 (A&P ch. 2)
4. Optical turbulence in the atmosphere (A&P ch. 3)

HW 1 due

Week 3

5. Optical turbulence profiles (A&P sec. 12.2)
6. Free-space propagation 1 (A&P ch. 4)

HW 2 assigned

Week 4

7. Free-space propagation 2 (A&P ch. 4)
8. Propagation through random media 1 (A&P ch. 5)

HW 2 due

Week 5
9. Propagation through random media 2 (A&P ch. 5)
10. Second-order statistics 1 (A&P ch. 6)
HW 3 assigned
Week 6
11. Second-order statistics 2 (A&P ch. 6)
12. Fourth-order statistics (A&P ch. 8)
HW 3 due
Week 7
13. System analysis 1 (A&P ch. 14)
14. System analysis 2 (A&P ch. 14)
HW 4 assigned
Week 8
15. In-class midterm exam
16. System analysis 3 (M&S ch. 3)
HW 4 due; Midterm oral review
Week 9
17. Classical control 1 (M&S ch. 5)
18. Classical control 2 (M&S ch. 5)
HW 5 assigned
Week 10
19. Modern control 1 (M&S ch. 6)
20. Modern control 2 (M&S ch. 6)
HW 5 due
Week 11
21. Random data 1 (M&S ch. 7)
22. Random data 2 (M&S ch. 7)
HW 6 assigned
Week 12
23. Small-angle control (M&S ch. 11)
24. Large-angle control (M&S ch. 12)
HW 6 due
Week 13
25. Tracking 1 (M&S ch. 13)
26. Tracking 2 (M&S ch. 13)
HW 7 assigned
Week 14
27. Adaptive optics 1 (M&S ch. 14)
28. Adaptive optics 2 (M&S ch. 14)
HW 7 due
Week 15
29. Make up lecture (if needed)
30. Course conclusion and final exam review session (open discussion)
Take-home final exam assigned
Finals Week
Take-home final exam due; Final oral review

Grading:

Homework	35 points
Class participation	5 points
In-class midterm exam	25 points
Midterm oral review	5 points
Take-home final exam	25 points
Final oral review	5 points

As scheduled above, there will be seven graded homework assignments worth 5 points each. These assignments will prepare you for the in-class midterm exam and the take-home final exam. Class participation (i.e., class attendance, asking questions, study groups, etc.) will also prepare you for these exams. The midterm and final oral reviews will be one on one with the instructor (for at least 10 mins) to go over your graded exams. You will receive full credit on both reviews if you come prepared to discuss the reasoning behind your answers or where you think you went wrong. Your graded midterm exam will be handed back to you at least 24 hours before your scheduled midterm oral review. Your graded final exam, on the other hand, will be handed back to you at the start of your final oral review.

There are 100 points possible in the class (plus extra credit – see below). As the course progresses and you lose points on graded homework assignments, you should immediately know where your grade stands relative to the following rubric.

A, >89.5 points; B, > 79.5 points; C, >69.5 points; D, >59.5 points; E, 59.5 points or lower

If there is still doubt about your grade at any time during the course, then please do not hesitate to ask for clarification.

Extra Credit:
Mistakes found in the lectures or course materials will result in half a point of extra credit. Please email me with your findings if they are not pointed out in class. A thoughtful suggestion on how to improve the course material will result in 1 point of extra credit. Each student will be limited to 5 points of extra credit during the semester.

Academic Integrity:
You may refer to notes from other versions of this course (previous offerings at UA and other universities), and you may use homework solutions from outside this course. Students may collaborate on solving homework problems, but each student must submit his/her own copy of their solutions for each assigned homework set. In my view, directly copying another student's solution without supplying your own effort to solve any steps in the problem is cheating.

The in-class midterm exam and take-home final exam will be completed by yourself without the help of your fellow classmates. These exams will be open book and open note. Keep in mind that if you do somehow cheat on these exams (e.g., blindly using AI), then you will not be prepared to go over your graded exams during the post-exam oral reviews.

Cheating of any kind will be prosecuted and may result in any or all of the following:

- Reduction of grade
- Failing grade
- Referral to the Dean of Students for consideration of additional penalty

Accessibility and Accommodations

At the University of Arizona, we strive to make learning experiences as accessible as possible. If you anticipate or experience barriers based on disability or pregnancy, please contact the Disability Resource Center (520-621-3268, https://drc.arizona.edu/) to establish reasonable accommodations.

Subject to Change Notice

The information contained in the course syllabus, other than the grade and absence policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor.