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:
Background in Fourier optics

Location and Times:
Meinel 305, T/TH 1530-1645 MST
D2L site: https://d2l.arizona.edu/d2l/home/1781289

Instructor:
Prof. Mark Spencer
spencerm@arizona.edu
(520) 621-2927
Office hours: T/TH 1200-1300 MST in Meinel 737 or by appointment

TA:
N/A

Learning Outcomes:
- Understand the fundamentals of laser beam propagation through random media
- Analyze multiple scenarios of interest in terms of derived parameters
- Design laser systems that sense and correct for aberrations
- 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

HW 1 assigned

1. Linear systems and Fourier optics
2. Imaging systems in terms of isoplanatic aberrations

Week 2

HW 1 solutions posted

3. Imaging systems in terms of anisoplanatic aberrations
4. Split-step beam propagation method

HW 1 due

Week 3

HW 2 assigned

5. Random processes and fields
6. Rytov approximation

HW 1 due (Distance Learning)

Week 4

HW 2 solutions posted

7. Rytov number
8. Wave structure function

HW 2 due

Week 5

HW 3 assigned

9. Log irradiance variance, scintillation index, and Fried parameter
10. Spatial coherence radius, isoplanatic angle, and Greenwood frequency

HW 2 due (Distance Learning)

Week 6

HW 3 solutions posted

11. Tyler frequency
12. Scenarios of interest

HW 3 due

Week 7

HW 4 assigned

13. Thermal blooming
14. Aero-optics

HW 3 due (Distance Learning)

Week 8

HW 4 solutions posted

15. Scaling laws and error budgets 1

In-class midterm exam

HW 4 due

Week 9

HW 5 assigned; Midterm oral reviews scheduled

16. Scaling laws and error budgets 2
17. Classical control 1

HW 4 due (Distance Learning)

Week 10

HW 5 solutions posted

18. Classical control 2
19. Modern control 1

HW 5 due

Week 11

HW 6 assigned

20. Modern control 2

Colloquium

HW 5 due (Distance Learning)

Week 12

HW 6 solutions posted

21. Random data 1
22. Random data 2

HW 6 due

Week 13

HW 7 assigned

23. Large-angle control

24. Small-angle control
HW 6 due (Distance Learning)

Week 14

HW 7 solutions posted
25. Tracking
Thanksgiving
HW 7 due

Week 15

Take-home final exam assigned
26. Adaptive optics 1
27. Adaptive optics 2
HW 7 due (Distance Learning)

Week 16

28. Course conclusion and final exam review session
Final oral reviews scheduled
Take-home final exam due
Take-home final exam due (Distance Learning)

Finals Week

Final oral reviews

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. Lastly, if you miss one (or more) of the graded homework assignments,

then you will forfeit all class participation points.

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 or using generative AI 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 generative 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.