OPTI 512R: Linear Systems, Fourier Transforms

Fall 2026 (3 credits)

Welcome!

Instructor: Meredith Kupinski
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Office/Workshop Hour: Wednesday 4:00 pm, Graduate Lounge, Pizza Hour About Signal Education (PHASE). Canceled: 9/23, 11/11, 11/25, 12/9, see D2L
Lecture: Monday & Wednesday, 11:00 am–12:15 pm, Meinel 307
Course Website: https://d2l.arizona.edu

Teaching Assistant: Yukun Long
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TA Office Hours: Tuesday 3:30 PM
Location: Meinel 554; zoom by appointment
Final Exam: Monday, December 14, 10:30 am–12:30 pm; location announced on D2L

This course introduces linear operators and Fourier analysis as a unified language for optical science. The emphasis is on imaging, diffraction, propagation, and image formation, with explicit connections among continuous physical fields, abstract operators, sampled data, and numerical Fourier transforms. The course provides enough theoretical foundation to understand the assumptions behind tools that students will use throughout their careers.

Course Description. OPTI 512R, Linear Systems, Fourier Transforms (3 credits): linear-system theory; Fourier optics; interference and diffraction; image formation; and optical transfer functions.

Recommended preparation. Undergraduate linear algebra, multivariable and vector calculus, differential equations, complex numbers, and introductory wave physics. Prior coursework in complex analysis is helpful but not required.

Course delivery and participation. Lectures are delivered in person and asynchronously online for students enrolled in the distance-learning section. Access information and recording availability will be posted on D2L. Recordings are intended to support review and distance participation but are not guaranteed in the event of technical failure. Attendance is expected but is not directly graded; students are responsible for announcements, demonstrations, and material presented in class. PHASE workshop participation is optional.

Communications. D2L is the primary location for announcements, assignments, solutions, readings, and course questions. Weekly D2L discussion prompts are intended to support learning and are not graded unless an assignment explicitly says otherwise. For direct communication with the instructor or TA, use D2L email or University email with “OPTI 512R” in the subject line. A response is normally expected within 24–48 hours on business days.

Expected workload. As a three-credit graduate course, students should plan for approximately 6–9 hours per week outside scheduled class meetings for reading, problem solving, computation, review, and exam preparation. The time required will vary with prior preparation.

Expected Learning Outcomes

By the end of the course, students will be able to:

1. Represent optical fields, images, and imaging systems using finite- and infinite-dimensional vector spaces and linear operators.
2. Apply inner products, projections, adjoints, eigenanalysis, singular-value decomposition, and pseudoinverses to optical-system models.
3. Determine when a system is linear or shift invariant and derive its impulse-response and convolution representation.
4. Use and interpret Fourier series, continuous Fourier transforms, multidimensional transforms, and discrete Fourier transforms.
5. Derive the relationship among continuous functions, sampled data, finite measurement windows, periodization, and DFT output.
6. Predict and diagnose aliasing, spectral leakage, discrete convolution with modulo-N indexing (circular convolution), zero-padding effects, and Fourier-domain coordinate or normalization errors.
7. Derive and apply angular-spectrum, Fresnel, and Fraunhofer propagation models while identifying their physical assumptions.
8. Analyze coherent and incoherent imaging systems using pupils, point-spread functions, transfer functions, and spatial-frequency concepts.
9. Validate analytical and computational results using units, limiting cases, sampling checks, and physical interpretation.

Course Materials and Software

A desktop or laptop computer is required. University library laptops may be borrowed through the University Libraries technology-lending program.

Computational assignments may be completed in MATLAB or Python. Starter notebooks and common utility functions will be provided when appropriate. The purpose of the computational work is interpretation and validation, not proficiency in a particular programming language.

Required text H. H. Barrett and K. J. Myers, *Foundations of Image Science*. Selected chapters are available through the Polarization Lab resources page and D2L.

Recommended resources

- J. D. Gaskill, *Linear Systems, Fourier Transforms, and Optics*.
- J. W. Goodman, *Introduction to Fourier Optics*.
- R. N. Bracewell, *The Fourier Transform and Its Applications*.
- J. S. Tyo and A. Alenin, *Field Guide to Linear Systems in Optics*.
- J. Schwiegerling, OPTI 512R archive.
- M. Mansuripur, "Ubiquity of Fourier Transformation in Optical Sciences."

Course Assessments

Assignments. Twelve assignments will combine analytical problem solving with computational interpretation. At least three assignments will include substantial computational work, including FFT literacy and numerical propagation or imaging. Assignments and solutions will be distributed through D2L. Unless otherwise stated, work is due at 11:59 pm Arizona time on the listed date.

To permit timely release of solutions, the late policy is:

- within 24 hours of the due date: 10% deduction;
- within one week of the due date: 20% deduction;
- more than one week late, if solutions have not yet been released: maximum attainable score of 50%.

Each student has one late pass that permits one assignment to be submitted up to one week late without a grade reduction. Solutions will normally be released approximately one week after the due date. Once solutions are released, the original assignment will no longer be accepted; an alternate assignment may be arranged only through an approved accommodation or prior agreement with the instructor. On-time work will normally be returned within one week; late work will normally be returned within two weeks.

Submit one legible PDF per analytical assignment. Include your name and problem number on each page. Submit computational notebooks and any requested PDF summary using the naming convention posted on D2L. Only D2L submissions will be accepted unless an accommodation or technical problem has been arranged.

Exams. One 75-minute midterm and one two-hour cumulative final examination will be given. Exams are open notes, and use of the course equation sheets is encouraged. Computers, tablets, phones, generative-AI systems, and networked devices are not permitted. Instructions for synchronous distance students will be provided in advance.

Grading

Item	**Percentage**
12 assignments	50%
Midterm examination (October 21)	25%
Final examination (December 14)	25%

Letter-grade scale. Final course grades will be assigned using the following thresholds: A = 90–100%, B = 80–89.99%, C = 70–79.99%, D = 60–69.99%, and E = below 60%. The instructor may lower, but will not raise, these thresholds.

Course Schedule

The schedule is organized in four units. Readings and assignment details will be posted weekly on D2L. Adjustments may be made with advance notice.

Date	Topic	Assessment
Unit I: Optical systems as operators		
Aug. 24	Course introduction: an imaging system in continuous, operator, sampled, and numerical representations	–
Aug. 26	Vector spaces, functions as vectors, inner products, norms, and basis functions	Assignment 1 posted
Aug. 31	Adjoints, projections, and eigenanalysis	Assignment 1 due Sept. 1
Sept. 2	Singular-value decomposition, range and null spaces, and pseudoinverses	Assignment 2 posted
Sept. 7	**No class – Labor Day**	Assignment 2 due Sept. 8
Sept. 9	Continuous-to-continuous, continuous-to-discrete, and discrete-to-discrete operators; linearity	Assignment 3 posted
Sept. 14	Shift invariance, impulse response, convolution, and linear shift-invariant systems	Assignment 3 due Sept. 15
Sept. 16	Dirac delta distributions, generalized functions, and sampling combs	Assignment 4 posted
Unit II: Fourier representation and computation		
Sept. 21	Continuous bases, Fourier series, orthogonality, and basis expansion	Assignment 4 due Sept. 22
Sept. 23	Fourier-series convergence and Gibbs phenomenon (GUEST LECTURE)	Assignment 5 posted
Sept. 28	Continuous Fourier transform and transform pairs	Assignment 5 due Sept. 29
Sept. 30	Fourier-transform properties, convolution theorem, Parseval, and Wiener–Khinchin	Assignment 6 posted
Oct. 5	Sampling theory, reconstruction, and aliasing (GUEST LECTURE)	Assignment 6 due Oct. 6
Oct. 7	Space-limited, band-limited, and finite-record functions; windowing and leakage (GUEST LECTURE)	Assignment 7 posted
Oct. 12	Multidimensional Fourier transforms and coordinate systems	Assignment 7 due Oct. 13
Oct. 14	Deriving the DFT from sampling, finite support, and periodization	Assignment 8 posted
Oct. 19	Computational studio: FFT scaling, physical frequency axes, shifts, modulo-N convolution, and zero-padding	Assignment 8 due Oct. 20
Oct. 21	**Midterm examination**	–
Unit III: Propagation as a linear system		
Oct. 26	Scalar wave equation, assumptions, and Green's functions	Assignment 9 posted
Oct. 28	Plane waves, propagation eigenfunctions, and angular-spectrum propagation	Assignment 9 due Nov. 3
Nov. 2	Huygens–Fresnel principle and diffraction integrals	Assignment 10 posted
Nov. 4	Fresnel and Fraunhofer approximations; stationary phase	Assignment 10 due Nov. 10
Nov. 9	Lens as a Fourier transformer; 4f systems and spatial filtering	Assignment 11 posted
Nov. 11	**No class – Veterans Day**	–
Unit IV: Image formation and synthesis		
Nov. 16	Coherent imaging: pupil, amplitude point-spread function, and coherent transfer function	–
Nov. 18	Incoherent imaging: intensity PSF, OTF, MTF, and pupil autocorrelation	Assignment 11 due Nov. 24

Date	Topic	Assessment
Nov. 23	Aberrated pupils, image quality, and spatial-frequency interpretation	Assignment 12 posted
Nov. 25	Computational clinic and optional individual meetings; no indispensable new content	–
Nov. 30	Application lecture: DFTs in polarimetry and computational imaging (GUEST LECTURE)	–
Dec. 2	Selected phenomena: Talbot effect, Babinet's principle and the Arago spot, and the van Cittert–Zernike theorem	–
Dec. 7	Full-system synthesis: operator, propagation, sampling, and image-formation viewpoints	Assignment 12 due Dec. 8
Dec. 9	Final-exam preparation and course synthesis	–
Dec. 14	**FINAL EXAM, 10:30 am–12:30 pm**	

Recommended Reading Map

The readings below identify the conceptual spine of the course. Weekly D2L announcements will specify which sections should be read closely and which are provided for reference.

Unit I	Barrett and Myers, Chapter 1: Sections 1.1–1.7 (vector spaces, operators, eigenanalysis, SVD, pseudoinverse); Chapter 7: Sections 7.2–7.4 (continuous and discrete linear systems); Chapter 2: Sections 2.1–2.4 (distributions and delta functions).
Unit II	Barrett and Myers, Chapter 3: Sections 3.1–3.6 (Fourier series, continuous and multidimensional Fourier transforms, sampling, and the DFT).
Units III–IV	Barrett and Myers, Chapter 9: Sections 9.1–9.7 (wave equations, Green's functions, diffraction, propagation, point-object imaging, and extended-object imaging).

Intended Depth of Coverage

The categories below indicate the expected depth of engagement with each major area of the course. "Gain genuine theoretical exposure" means that students should understand the purpose and implications of a concept without necessarily reproducing every formal proof. The "Intrepid learner" will explore beyond the content presented and accessed in this course.

Material	Intended depth of coverage
Vectors and operators	**Learn for mastery.** Inner products, norms, orthogonality, bases, linear operators, adjoints, projections, range and null spaces, eigenanalysis, singular-value decomposition, and pseudoinverses. **Gain genuine theoretical exposure.** Completeness, boundedness, compactness, continuous bases, and why infinite-dimensional spaces differ from finite-dimensional spaces. **Available for the intrepid learner.** Detailed Banach-space results, most reproducing-kernel Hilbert-space theory, and lengthy proofs of the Penrose equations.
Delta functions	**Learn for mastery.** Sifting, shifts, derivatives, combs, convolution, and sampling. **Gain genuine theoretical exposure.** The delta function as a distribution rather than an infinite ordinary function; test functions; and why some products and limiting manipulations are not mathematically valid. **Available for the intrepid learner.** A broad formal theory of distributions and pathological generalized functions.
Fourier analysis	**Learn for mastery.** Distinctions among Fourier series, the continuous Fourier transform, and the discrete Fourier transform; orthogonality; convolution; Parseval's theorem; sampling; aliasing; reconstruction; windowing; finite records; scaling; and physical units. **Gain genuine theoretical exposure.** Convergence in different senses, generalized-function transforms, and the relationship between continuous and discrete operators. **Available for the intrepid learner.** Exhaustive convergence proofs and comprehensive memorization of transform identities.
Diffraction and imaging	**Learn for mastery.** Angular-spectrum propagation; Fresnel and Fraunhofer propagation; lenses as Fourier transformers; coherent and incoherent imaging; pupils; point-spread functions; optical and modulation transfer functions; and aberrations. **Gain genuine theoretical exposure.** Green's functions, assumptions underlying scalar-wave theory, and plane waves as eigenfunctions of shift-invariant propagation. **Available for the intrepid learner.** Long constitutive-medium derivations and the full vector electromagnetic development already covered in OPTI 501.

Collaboration, External Resources, and Generative AI

Collaboration. Students may discuss course concepts and general solution strategies with classmates. Each student must independently carry out and write the submitted analysis and code. Collaborators and substantive external resources must be acknowledged. Copying derivations, code, figures, or numerical output is not permitted.

Generative AI. Unless an assignment states otherwise, generative-AI tools may be used to clarify a concept, check an independently developed derivation, or assist with debugging code. They may not generate a submitted solution in place of the student's own reasoning. Any use must be disclosed briefly, including the tool and its purpose. Students remain responsible for every submitted statement, equation, and line of code and must be able to reproduce and explain their work. Generative AI is not permitted during examinations.

University Policies and Resources

Disability-related accommodations. Students seeking disability-related accommodations should register with the Disability Resource Center (DRC). Once an official accommodation notification is received, the instructor and student will work together to implement the approved accommodations. Students are encouraged to begin this process early.

Late registration. Students who register after the course begins may make up assignments that were due before registration. A plan should be arranged with the instructor before the midterm examination.

Academic integrity. Students are responsible for complying with University of Arizona policies on academic integrity. The collaboration and generative-AI rules above specify expectations for this course. When uncertain whether a form of assistance is permitted, ask before submitting the work.

Incomplete or withdrawal. Requests for an Incomplete (I) or Withdrawal (W) must follow the University grading policy.

University policies. Required policies are collected on the University syllabus-policies page.

Graduate student and basic-needs resources. Information about food, housing, transportation, health, and financial support is available through University basic-needs resources.

Subject to change. Information in this syllabus other than the grading policy may be revised with reasonable advance notice when changes improve course continuity or respond to University scheduling needs.

AI-use Acknowledgment

This syllabus was developed with assistance from OpenAI's ChatGPT (GPT-5.6 Thinking), which was used to help organize course content, refine language, and develop instructional materials. All content was reviewed and approved by the instructor, who assumes full responsibility for the final syllabus.