

A joint Electrical Engineering/Physics course sequence for optics fundamentals and design

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ABSTRACT

Optics is a key technology in a broad range of engineering and science applications of high national priority. Engineers and scientists with a sound background in this field are needed to preserve technical leadership and to establish new directions of research and development. To meet this educational need, a joint Electrical Engineering/Physics optics course sequence was created as PHYS 3445 Fundamentals of Optics and EE 4444 Optical Systems Design, both with a laboratory component. The objectives are to educate EE and Physics undergraduate students in the fundamentals of optics; in interdisciplinary problem solving; in design and analysis; in handling optical components; and in skills such as communications and team cooperation. Written technical reports in professional format are required, formal presentations are given, and participation in paper design contests is encouraged.

Keywords: Education, optics, team projects, oral and written communications.

1. INTRODUCTION

Photonic components, devices, and systems find use in various applications, for example, in optical fiber communications, medical instrumentation, laser technology, computing, data acquisition and analysis. Students in Electrical Engineering (EE) and Physics should be skilled, or at least knowledgeable, in the fundamentals of optics and the use of optical techniques in various types of applications. For students continuing into graduate school, a solid optics background with hands-on experience is good preparation for advanced level courses in optics, electromagnetics, microelectronics, communications, and other areas.

In most colleges and universities, optics is treated as part of a broader disciplinary academic program, such as Physics or Electrical Engineering.¹ However, optics permeates many disciplines and is, therefore, a fundamental science that serves as a basis for addressing many applied science and engineering applications and problems.² Furthermore, the level of student learning in the traditional format is being questioned.³ Specifically, comparison of learning by rote versus “functional understanding”³ reveals the true degree of student performance. Basically, can the student apply what has been learned to different types of problems? Does the student have a sufficiently deep understanding of concepts to apply them in different contexts?

To begin to address some of these issues, a joint Electrical Engineering/Physics two-course optics sequence has been developed. Both courses have an associated laboratory component. The first course, PHYS 3445, concentrates on the fundamentals of optics and photonics. The second course, EE 4444, emphasizes optical systems engineering and design. Both EE and Physics students are taught to handle, use, and apply optics and are exposed to realistic design, analysis, and manufacturing issues. Specific objectives include the following:

1. Enable functional learning of fundamentals and applications
2. Provide a design experience
3. Learn group dynamics through team projects
4. Cultivate creative thinking and problem solving skills
5. Facilitate use of library resources
6. Develop self-learning skills
7. Develop communications skills

8. Broaden perspective of students by introducing them to ongoing research activities
9. Prepare students for jobs
10. Prepare students for graduate school

Therefore, the philosophy of the project centers on educating the undergraduate engineering or science student not only on the fundamentals of optics but also on the concepts of interdisciplinary problem-solving; on design, analysis, and manufacturing issues; on handling and using optics in a variety of applications; on self-learning; and on developing other important skills such as communications and interpersonal relations. The course sequence gives students the opportunity to apply their strength in fundamentals to important applications. Similarly, the sequence provides students with an in-depth background in optics, giving them greater potential for solving problems by optical techniques or for developing new ideas. Going beyond the course sequence, students may elect to continue to develop their various skills by participating in student paper design competitions and in undergraduate research activities.

Previously, the Electrical Engineering and Physics Depts. at UTA offered separate courses in optics covering similar topics. One goal of this curriculum project was to encourage Physics and EE students to enroll jointly in the 2-course sequence and learn how to work together in teams on design projects, thus preparing them for employment in industry or for research in graduate school. Historically, the philosophy of *disciplinary* education has been very strong at UTA. Therefore, the students typically remained in their home departments for their coursework and never ventured to other departments for a broader perspective.

This paper presents a summary of the new optics course sequence and its impact on student learning and undergraduate research. An overview of the two courses is presented followed by a discussion of activities beyond the courses including student paper design competitions and undergraduate research.

2. COURSE SEQUENCE

2.1. PHYS 3445 Fundamentals of Optics

2.1.1 Lecture topics

The text for this course is Ref. 4. The class lectures emphasize the mathematics of waves and physical optics. The chief topics are: harmonic electromagnetic plane waves in three dimensions, refraction and reflection, polarization, interference, and diffraction. The complex representation of waves is stressed as is the vector nature of light and the principle of superposition. The local plane wave approximation to propagating spherical waves, finite beams, and Gaussian beams is developed. Fourier optics is introduced in the context of diffraction theory. Evanescent waves, optical coupling, guided waves, and non-linear optics are introduced. Geometric optics is presented as the limit of non-diffracting beams and ray optics is limited to simple lens systems.

The laboratory experience is intended to be the major trust of PHYS 3445 as reflected in the lectures. The laboratory topics are addressed briefly in lecture and the students' experimental results are correlated with the lecture as examples. Additional feedback from the lab is obtained during a question and answer session.

2.1.2 Laboratory experiments

The first laboratory session is focused on procedures and safety; all lasers are treated as eye hazards.⁵ The safety of personnel and equipment is emphasized. The laboratory experiments are carried out by groups of students of two or three. Laboratory handouts based on the lab manual⁶ and on the workbook produced by Newport⁷ are supplied. Laboratory reports, prepared by the individual students, are graded and corrected. The following are the main experiments conducted:

- 1. Reflection and refraction.** In this experiment the students verify the laws of reflection and refraction for materials with different indices of refraction and gain hands-on experience with a laser light source, mounts, and optics.
- 2. Diffraction.** Diffraction from a single slit, double slit, and a circular aperture. Observations of the Poisson spot, along with verification of Young's double slit experiment, are made.
- 3. Ray-tracing-matrix method.** Ray tracing is introduced using the ABCD matrix method. The students design a Keplerian and Galilean beam expander and verify the size of the expanded beam by calculations. Also, optical design software is used to verify the results.

4. Bovine Eye. The dissection of a bovine eye is used to demonstrate the uniqueness of the eye as an optical instrument. All the parts of the eye are identified the birefringence property of the lens is observed.

5. Transmission, reflection, and polarization. The transmission and reflection of S and P polarization are measured for different angles including the Brewster angle. Students also perform an experiment using $\frac{1}{2}$ and $\frac{1}{4}$ waveplates.

6. Characterization of lasers. The divergence, polarization efficiency, spot drift, and power stability of a gas laser, diode laser, and a solid-state laser are measured.

7. Abbe-Porter experiment. An introduction to Fourier optics and Fourier-plane spatial filtering.

8. Michelson interferometer. The students conduct vibration analysis, aberration measurements, and laser coherence studies.

Table 1.	PHYS 3445 Chief Experiments
1	Reflection and refraction
2	Diffraction
3	Ray tracing – matrix methods
4	Boivine eye
5	Transmission, reflection, and polarization
6	Characterization of lasers
7	Abbe-Porter experiment
8	Michelson interferometer

2.1.3 Group projects

Approximately mid semester the established working laboratory groups are assigned projects. Some of the students may be working on suitable projects related to sponsored research; others come up with independent ideas that can be accommodated with existing facilities and equipment. The faculty and teaching assistants confer with the group members and the students are allowed several options for projects. Effort is made to match expressed interest. Each group prepares a working laboratory demonstration and a poster for presentation in an undergraduate research symposium (sec. 3).

Table 2.	Example PHYS 3445 Projects
1	Computer-generated holographic optical elements for the far infrared spectral region
2	Sub-wavelength diffraction gratings on GaAs wafers for use in vertical cavity laser development
3	Examination of an unknown lens system using a collimator and an optical bench
4	Vibrational analysis using interferometry
5	Optical waveguide fabrication
6	Twyman-Green interferometer
7	Generation of holographic images using a spatial light modulator
8	Guided mode waveguide coupling

2.2. EE 4444 Optical Systems Design Capstone

2.2.1 Lecture topics

Reference 8 is the text for EE 4444. The following topics are presented: ABCD matrices, electromagnetic theory of light propagation, Gaussian beams, birefringent elements (wave plates, polarizers, etc.), electro-optic modulation, photorefractive, diffractive optics, Fourier optics and holography, nonlinear optics (second harmonic generation and all-optical switching), fiber optics, acousto-optics, and lasers. Handouts of the notes are provided for the students to allow a faster pace lecture. Topics are reinforced through the laboratory exercises.

2.2.2 Laboratory

The laboratory exercises summarized below are completed as part of the formal course. Students are organized into teams of 3. They are assigned several (~8) experiments which takes approximately 1/2 semester.

1	Fiber optics
2	Imaging and aberrations
3	Optical imaging system design
4	Polarization and birefringence
5	Fourier optics/optical filtering
6	Michelson interferometer
7	Two-beam transmission holography
8	Thin film design
9	Electro-optic modulation

1. Fiber Optics System Design. Topics include numerical aperture, fiber attenuation, single mode fibers, polarization maintaining fibers, coupling to individual fiber modes, coupling fibers to semiconductor sources, connectors and splices, fiber-optic communication link, multimode intensity sensors, interferometric sensors, spectra of LED's and laser diodes on fiber-optic coupled spectrum analyzer.

2. Imaging and aberrations. Imaging with refractive optics, thin-lens equation, resolution of optical systems, depth of focus, imaging with diffractive optics, aberrations (chromatic, spherical, astigmatism).

3. Polarization properties of light. Linear, circular, and elliptical polarization, Brewster's angle, Birefringence (Calcite, KDP), interference figures of crystals, optical activity, amplitude modulation of laser light.

4. Fourier Optics. Beam collimation, Fresnel and Fraunhofer diffraction of various transparencies, Fourier transform spectra of periodic and nonperiodic objects, properties of the Fourier transform, various filtering operations in the Fourier plane.

5. Holography. Several basic projects such as two-beam transmission holograms, reflection holograms, holographic interferometry.

6. Interferometers. Michelson interferometer, visualization of fringe displacement with optical path length changes.

7. Optical systems design using commercial software. A large variety of practical systems can be handled with the available software. Exercises include thin-film and imaging-system design.

2.2.3. Team projects

Team projects emphasize design concepts and sharpen the understanding of optics and its uses. Student teams are formed during the first two weeks of the semester with each one selecting a team leader. A list of design topics is provided, but the students are not limited to it. Each team submits a one-page project proposal with title, abstract, specific objectives, and a major reference. In addition, each team presents their proposal (Design Review 1); typically, only the team leader speaks at this point. The professor meets with each team periodically to ensure that they remain focused and on schedule.

After three to four weeks each team submits a progress report (1-2 pages) describing their interim results, any refinements to the objectives, and any technical or personnel problems. Oral presentations are given in Design Review 2, and each team member is required to make a statement of their role in the overall project.

At the end of the semester, each team submits a single final report, complete with figures and references. The students are evaluated on the quality of the work, on organization of its presentation, on adherence to rules in grammar and on format of references (IEEE), on quality of the references cited, and on neatness. This session is run much like a technical conference, with presentations limited to 15 minutes with 5 minutes for questions. The team leader must organize the structure of the overall presentation of the project. Each team member is required to speak. The team is evaluated on the technical content, presentation skills, the flow of their presentations, and their ability to answer questions. Because of time and cost limitations, most teams deliver design studies rather than full experimental implementation of a design.

Table 4. Reports and oral presentations
Class Reports
Proposal (1 page)
Progress Report (1-2 pages)
Final Report (1 report per team)
Class Presentations
Design Review 1
Design Review 2
Final Presentation

Table 5. Example EE 4444 Design projects
Wavelength division multiplexing for optical communications
Bar code reader design
Design of a laser cancer detection system
Holographic computer memory
Fiber-optical illumination system for buildings
Optical targeting system
Erbium-doped fiber-optic amplifier systems
Laser range finder
System for laser eye surgery
Second-harmonic generation in ionic self-assembled monolayer coated optical fibers
Optical fingerprint recognition system

3. UNDERGRADUATE RESEARCH SYMPOSIUM

Each year UT Arlington hosts the Symposium for Undergraduate Research and Creative Activity (SURCA). SURCA is a university-wide forum for undergraduate scholars from all colleges and programs on campus to present their work. The event, which is held each April, includes four parallel sessions of oral presentations, followed by a poster session. Each session includes a mix of presentations from engineering, science, business, liberal arts, music, social work, etc. The panel of judges for each room is also mixed. At the end the student winners are recognized at an awards ceremony and presented with monetary awards and a certificate. A reception is held while the judges meet to select the winners. EE 4444 student teams have always been encouraged to participate. In Spring 1999 the entire PHYS 3445 class was required to participate as part of their course grade, and a couple of the teams from the Fall 1998 EE 4444 class participated as well.

4. PAPER DESIGN CONTESTS

Some of the project teams have continued their work beyond the optics sequence. As part of the courses, the students are informed of upcoming paper design contests from various professional organizations IEEE (regional, state, national, and local), DFW IEEE Lasers and Electro-optics Society (LEOS), National Society of Black Engineers, and others. Individual team members compete in these contests rather than the team together. In 1999 one EE 4444 student won first place in the Fort Worth IEEE Paper Contest on her project, "Optical Fingerprint Recognition System." She then competed in the IEEE Region 5 competition. Another student from the same EE 4444 project team placed second nationally at the National Society of Black Engineers annual conference. In 1996 an EE 4444 student won first place at the IEEE Region 5 competition for her project, "Fiber Optic Light Illumination System for Photonic Antennas."

5. UNDERGRADUATE RESEARCH

UT Arlington has promoted undergraduate research over the years, as evidenced by its support of the annual Symposium on Undergraduate Research and Creative Activity. There are several programs on campus which provide scholarship funds for undergraduates to participate in research activities, including the Ronald E. McNair Baccalaureate Achievement Program, NSF Alliance for Minority Participation (AMP) in Research, and two NSF Research Experiences for Undergraduates programs, one of them in the EE Dept.

Since 1985 UT Arlington's Department of Electrical Engineering has conducted a program involving undergraduate scholars in research projects. In 1991 UTA EE became a NSF Research Experiences for Undergraduates (REU) site. The objective is to seek participation of undergraduate scholars in ongoing funded research projects with significant interaction between faculty, graduate students, and the REU scholars. An academic year component, open to all qualified UTA EE students, and a summer component, designed to emphasize the participation of underrepresented minorities, are in place. REU activities include selecting a research topic with a faculty mentor, writing a research proposal, conducting the research, analyzing data, writing progress and final reports, presenting the work orally, and performing an ethics study. The optics course sequence has been a direct source of REU scholars in optics. Many of them subsequently enroll in the EE or Physics graduate program.

6. GRADUATE PROGRAM

For students interested in continued studies in optics, the following graduate courses are available:

- Lasers and applications
- Diffractive optics
- Fourier optics and holography
- Integrated optics
- Fiber optic transmission systems
- Advanced quantum devices
- Nonlinear optics
- Semiconductor devices
- Optoelectronics

7. SUMMARY

In summary, the chief objectives of this project are to streamline optics education in traditional EE/Physics curricula, increase hands-on/lab experience, strengthen optics background of graduates, and to develop well-prepared GRAs. Thus, emphasis was placed on team problem solving, design, analysis, and manufacturing issues, handling/using optical components in applications, perspective on current state of technology, and on written and oral communication. The optics course sequence serves as a vehicle for students to continue graduate studies in optics in addition to preparing students for careers in industry.

ACKNOWLEDGMENTS

This curriculum project was supported by a National Science Foundation Instrumentation and Laboratory Improvement (ILI) grant DUE-9552066. The Dean of Engineering, the Dean of Science, and the Vice Provost for Research at The University of Texas at Arlington supported this project by providing matching funds. We thank Eric Livesay and Robert Angelopoulos for their help in developing the PHYS 3445 laboratory and Sorin Tibuleac for his work on developing the EE 4444 lab. Paul Draper helped write the original ILI proposal. The undergraduate research program in Electrical Engineering is supported by National Science Foundation Research Experiences for Undergraduates grant EEC-9820496.

REFERENCES

1. D. G. Hall and R. C. Powell, "Optics education: encouraging an integrated approach," *Opt. and Photon. News* **9**, pp.18-22, September 1998.
2. B. L. Anderson, L. J. Pelz, S. A. Ringel, B. D. Clymer, and S. A. Collins, Jr., "Photonics laboratory with emphasis on technical diversity," *IEEE Trans. Ed.* **41**, pp. 194-201, August 1998.

3. P. R. L. Heron and L. C. McDermott, "Bridging the gap between teaching and learning in geometrical optics: The role of research," *Opt. and Photon. News* **9**, pp. 30-36, September 1998.
4. E. Hecht, *Optics*, 3rd Ed., Addison-Wesley, Reading, 1998.
5. D. H. Sliney, Laser and LED eye hazards: Safety standards, *Opt. and Photon. News* **8**, pp. 31-37, September 1997.
6. A Physics 3445 Optics Laboratory Manual has been produced for several years. This manual reflects the availability of equipment; it is augmented and revised each year.
7. Projects in Optics, Applications Workbook, Newport Corporation, No. 16291-01.
8. B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics*, Wiley, New York, 1991.