Teaching optical engineering to electrical-engineering undergraduates

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ABSTRACT

We describe a one-semester undergraduate course in Optical Engineering that has been taught at University of Central Florida since 1985 to junior and senior students of electrical engineering. The choice of topics emphasizes first-order system-engineering calculations, rather than the more traditional theoretical viewpoint often found in junior/senior-level optics courses. Representative topics include: paraxial raytracing, field of view and F/#, diffraction-limited resolution, Fresnel equations, radiometric/photometric units, paraxial flux transfer, blackbody radiation, detector responsivity and sensitivity, shot noise, Johnson noise, and laser-beam propagation. Homework problems emphasize estimation of magnitudes, as well as more exact numerical calculations. We have found this approach to be accessible to typical engineering undergraduates, and to be a good foundation for entry-level practitioners.

Keywords: optics education, engineering education.

1. INTRODUCTION

Our objective in this course is to teach some useful optics to electrical engineering undergraduate students. Only one semester is available in a crowded and hours-constrained program, and the students have no prior background in optics. They do possess a typical junior/senior-level background in EE, which can include electronics, communications, solid-state devices, and electromagnetics, but there is essentially no uniformity of prerequisite enforcement. The questions we asked in the design of this course under these constraints are: what is important for an entry-level EE to know about optics?; what content and level of material is accessible, given the limitations of time and background preparation?

2. COURSE DESIGN PHILOSOPHY

We followed two guiding principles in the course design. We chose to emphasize concepts related to first-order optical-engineering calculations, since an engineer's job often involves making approximations as a starting point. These "back of the envelope" estimates are typically refined empirically in the laboratory or by more exact calculation. Also, the course should also provide a framework of basic knowledge that can be built upon, fitting in concepts from further study.

We wanted a course that would be a practical preparation for entry-level EE's if they should encounter optics-related issues on the job. The sorts of optics questions likely to confront the new engineer (...having taken an optics class, is he/she the local expert..?) can include: "Where is the image and how big is it? Can we change this?"; "What do all these rays mean in an optical diagram?"; "How much power is transferred to the image?"; "How much power is lost to reflection in this window?"; "Why is the image blurry and what can be done about it?"; "Is the imaging system diffraction limited?"; "What size pinhole do you use with a 10x microscope objective in a spatial filter?"; "What does collimation ('image at infinity') mean?"; "What determines field of view?"; "Does the detector size in the CCD array make a difference to image quality?"; "How much power can you couple into a fiber?"; "How much does this source emit in the 8-12 μm band?"; "How much power gets to the detector?"; "What can be done to increase the signal-to-noise ratio?"; "Why do we need to cool the detector?"; "What good does the lock-in amplifier do?"; "With a beam FWHM of 5 mm, what lens aperture do we need?"; "How fast does the laser beam diverge?"; "How do we measure the beam size?"; and so on.

However, the viewpoint often found in first-level optics courses does not really prepare students for this. Traditional courses emphasize fundamental-physics phenomena and derivations (Maxwell's equations, Fresnel equations, Fresnel and Fraunhofer diffraction, matrix raytracing, coherence, anisotropic media, rate equations, etc.). These are all good things for the student to know, but under the constraint of a one-semester course with no prior optics background, are they the most pertinent topics?

The issues that entry-level EEs encounter in an optics-laboratory environment typically concern imaging, flux transfer, detection, and interference. The University of Central Florida has offered a three-credit one-semester EE optics elective course each year since 1985, which emphasizes these topics. The typical class size is 35 students. Plentiful homework (13 homework sets in a 16-week course) is assigned and graded, which emphasize estimation of magnitudes, as well as more exact numerical calculations. We feel that along with the concepts, a facility with calculations is also important to the engineering student, since an entry-level engineer should be able to quickly make calculations that are accurate to within 10%.

3. CHOICE OF TOPICS

3.1. Imaging (4 weeks)

Wavelength, frequency, refractive index, ray concept
Fresnel equations for reflected and transmitted *power*
    (restriction to normal incidence avoids polarization issues)
Snells Law
    thin prisms, TIR, confinement in fibers
Optical materials (descriptive)
    metals, dielectrics: spectral transmittance and reflectance
Focal length and lens maker's equation
Graphical raytrace rules (insight to why the rays go where they do)
Imaging equation (single lens imaging)
Aperture stop, field stop, marginal ray, chief ray
F/# and field of view
Paraxial raytrace rules for thin lenses
    lens combinations (telescopes, relay lenses, collimators)
    calculate image size and location, find stops
Image quality
    diffraction spot size: 2.4λ F/#
    aberrations - functional dependence on F/# and FOV
    defocus & focusing tolerance

3.2. Flux transfer (4 weeks)

Radiometric units (power- and photon-based)
    intensity, irradiance, radiance, exitance
Area solid-angle product: throughput
Lambertian radiators
Extended sources vs. point sources
Flux transfer calculations: imaging and non-imaging
Spectral "per micron" units
Planck equation calculations: spectral, in-band, and total flux
Wien Law
Emissivity and graybody radiation
Gaussian beams
    beam waist size "w parameter"
    encircled energy
    FWHM and other widths, related to "w"
    propagation equation "w" vs. z
    divergence angle, rayleigh range, focusing

3.3. Detection (4 weeks)

Responsivity vs. sensitivity
Thermal vs. photon detectors
- response speed
- spectral responsivity

Energy gap in photon detectors
- cooling requirements

Response time and bandwidth
Noise
- quadrature addition of rms quantities
- power spectrum
- shot & G-R noise (signal, background, dark-current)
- Johnson noise
- bandwidth dependence

Noise equivalent power and signal-to-noise ratio
Detection mechansims
- Photovoltaics
- Photoconductors
- Bolometers
- Pyroelectrics

3.4. Interference (2 weeks)

Superposition of waves
Optical-path length and interference
- Thin film antireflection coating
- Young's double slit
- Diffraction grating

Surely many other topics are possible and desirable, but in our experience, the topics above are just able to be covered adequately within one semester.

4. OBSERVATIONS & CONCLUSIONS

This approach and content is accessible to typical EE undergraduates, in a one-semester course. The material is taught from xeroxed notes made available to the students, as no book is currently available with this particular viewpoint and coverage. A textbook is in preparation, probably complete in 1999. There are only two free technical electives in our undergraduate EE program. If the student takes a second elective in optics, it is typically the graduate laboratory class. Alumni feedback since 1985 indicates this is a solid foundation for entry-level engineering practitioners, as well as forming a conceptual framework for further study at the graduate level.

The author would welcome your comments by electronic mail at BOREMAN@CREOL.UCF.EDU.