Illumination Optics Course

Course Goals

How do experts find good solutions to problems in illumination optics? What happens in the head of an experienced optical designer? In this course, we give comprehensive insight into the deep physics and beautiful mathematics of illumination optics. We then fill the "toolbox" with methods and design elements. Finally, using a few archetypal examples, we show how to analyze problems from first principles, and how to use these insights and the toolbox to choose good design approaches.

Instructor

Julius Muschaweck, a German physicist, has been working on optical design for illumination for over twenty years. After a stay as Visiting Scholar at the University of Chicago with Prof. Roland Winston (well known as the originator of Nonimaging Optics), he was co-founder and CEO of OEC, an optical engineering service which pioneered freeform optics. Later, at OSRAM, where he held the position of Senior Principal Key Expert (the highest rank in the OSRAM/Siemens expert career), he coordinated the over 100 optical designers within OSRAM world-wide. He then joined ARRI, the leading movie camera and lamp head maker, as Principal Optical Scientist. Julius Muschaweck now works as an independent consultant, providing illumination optics solutions to industry clients, teaching courses on illumination optics, and writing about the subject. He is the author of over 25 scientific papers and the inventor of over 50 patent applications. He also loves to go hiking with his wife and their dog.

Content (five-day course)

Day 1:

- Optics basics (ray optics)
  - Spectrum / wavelength
  - What is a ray?
  - Refraction / reflection
- Radiometric/photometric quantities, incl. motivation and measurement
  - Radiometric vs. photometric
  - Radiant flux / luminous flux
  - Irradiance / illuminance
  - Radiant intensity / luminous intensity
  - Radiance / luminance
- Phase space definition (as simple as possible but no simpler)
  - Screens
  - A ray = four numbers = a point with four coordinates
  - Snell's law revisited
  - Phase space definition

  - Etendue definition
  - Skewness

Day 2:

- Photometric quantities in phase space
  - „Luminance is the density of flux in phase space“
  - Illuminance as weighted integral of luminance over solid angle
  - Intensity as weighted integral of luminance over area
  - Flux as 4D-integral of luminance over etendue
  - The “play dough analogy” and the “whipping cream analogy”
- Light sources and how to model them
  - Lambertian sources
  - LEDs
  - Traditional: Incandescent, fluorescent, HID
  - Physical / heuristic source models (spatial and angular apodization, volume)
  - Ray files

Day 3:

- Simulation of illumination optics systems
  - Ray tracing and the curse of Monte Carlo noise
  - Modeling object properties, and how that interacts with ray tracing
  - Source-optics-receiver
  - Measuring etendue with ray tracing software
- Design elements
  - Lenses
  - TIR lenses, and why the cannot be perfect collimators
  - Reflectors with and without facets, and what they do to etendue
  - Collimators: Simple lens/reflectors, CPCs, cones
  - Homogenizers:
    - Etendue-conserving:
      - Mixing rods
      - Fly’s eye condensers (double sided micro lens arrays)
    - Etendue increasing:
      - Single sided micro lens arrays
      - Diffuser plates
  - Dichroic filters

Day 4:

- Colorimetry and color mixing
  - Human color perception
  - CIE color spaces, with critique
  - Machine/camera color perception
  - Color rendering, CRI, CQS, TLCI, …
  - Color mixing with LEDs

        - Intuitive geometrical concept:
          Color mixing = vector addition in 3D X-Y-Z tristimulus space
        - LED binning and how it influences color
        - LED operating conditions and how they influence color
    - Color mixing optics
        - Homogenizers revisited
    - How can we quantify and measure homogeneity?
- Design methods / archetypal design approaches
    - Corralling the problem using the Physics fence,
      and understanding the problem from a bird's eye view
        - Light has quantity AND quality
        - Sufficient flux?
        - Sufficient luminance?
        - Does symmetry help us, or kill us? (Etendue squeezing / symmetry breaking)
    - When source etendue is small:
        - Point source method, possibly with scattering
            - Simple optics (lenses, paraboloidal/elliptical reflectors)
            - State of the art: Free form surfaces / Tailoring.
    - When source etendue is too large:
        - When full efficiency is important: STOP!
        - Otherwise: Understand and apply
          the luminance – etendue characteristic curve
        - Then continue as if „source etendue just right"
    - When source etendue is just right:
        - Often, very challenging problems
        - Understand edge rays
        - Build solution using etendue conserving elements
    - Optimization
    - How can we use ray tracing to understand the flow of light in a system?

Day 5:

- Archetypal design problems
    - Downlight, soft spot lights – a whole zoo of optical design options
    - Wall washing – with and without freeform optics
    - Hard edge spot lights – baffle projection vs. fly's eye condensers
    - Multi color Köhler Illumination
    - "Live" problems from the audience
- Freeform optics for illumination ("Tailoring")

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Julius Muschaweck