Overview of Stray Light
Part 1

Mary Turner
What IS stray light?

• What is stray light?
• Stray light refers to any unwanted light in an optical systems. Stray light is a problem in both imaging and non-imaging systems.
  • Generally concerned with light reaching the detector
• Stray light generally manifests itself in several different forms:
  • Ghosts
  • Scattered light
  • Straight paths due to improper baffling
  • Diffraction
  • Thermal emission
Ghosts

- Ghosts are images of bright sources
  - Usually out of focus
  - Caused by Fresnel reflections off the lens surfaces
    - Even orders of reflections can reach the image surface
  - Sources in or near the field of view can form ghosts
    - Sources outside the field of view must be considered
  - Small sources form images of the stop
  - Focused ghosts form images of the source
  - Reflection from sensor reimage on sensor
Ghosts

- A near pupil ghost creates “haze”
Ghosts

• Near ghost images form bright spots
  • Not a problem in Cooke
Ghosts

Ghost reflection off surface 3 then 1. (GH003001.ZMX)

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Marginal ray height : -23.8723
Chief ray height : -16.0714
Distance to ghost pupil: -50.9613
Distance to ghost focus: -67.2073
Effective focal length : 14.0764

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Scattered light

• Scattering can allow out-of-field source energy to reach image:
  • Eliminating results in vignetting/obscurcation of true field
  • Proper baffle design minimizes vignetting and improves rejection of scattered light
    • There will always be some vignetting if baffles are used
  • Paths may require one or many scatter interfaces
  • Baffle requirements change with source location:
    • Design must be evaluated over the range of viable conditions
Scattered light

- Optical and mechanical components contribute
  - Here on-axis only for analysis
Stray light

- Primary and Fresnels
  - 40um x 40um
Stray light

• Allowing for scattering effects
Stray light

- Signal lost in the noise
  - More pixels on large detector would help some, but...
Direct paths

- Light from out-of-field sources can reach detector if baffles are not properly designed.
  - “Properly designed” involve tradeoffs
Stray light

- https://www.camerahacker.com/Forums/Tips/Why_I_always_use_a_lens_hood.files.hidden/small_cropped%20light%20on%20lens.jpg
Diffraction

- Unwanted grating orders
- Edge diffraction sends energy in unwanted directions
Edge diffraction

- With spiders

https://thumbs.gfycat.com/PeppyAgreeableDevilfish-mobile.mp4

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Gratings

- Optical codes do not model gratings “physically”
Thermal emission

• All surfaces above 0K emit as blackbody radiators
  • Emitted energy has spectral distribution
Why is stray light a problem?

• In imaging systems, stray light reduces the overall contrast in the image:
  • Overall background is increased
  • Details can be “washed out”
  • Glare can obscure the real image
  • Auto-focus systems may not work properly
  • False signal (positives and negatives) can be produced
  • Radiometric measurements will be inaccurate
  • Components can be damaged (or destroyed)
When is it a problem?

• Stray light is always a concern in systems that
  • Require high contrast
  • Image faint objects
  • Make radiometric measurements
  • Transfer high power (such as laser beams)

(And any system where it was completely ignored)
Stray light analysis

- A systematic process used to isolate any unwanted light on the detector.
  - How much is there?
  - How did it get there?

- Carefully performed stray light analysis allows the designer to
  - Quantitatively determine the performance degradation due to stray light
    - Are the performance metrics compromised?
  - Determine the appropriate method(s) to fix any necessary problems
    - Not all stray light is “worth” fixing
Stray light analysis

• Inherently nonsequential or unconstrained analysis
  • Fresnel reflections
    • Most sequential design programs can model to some level of accuracy
    • Good 1st step
    • Don’t wait until design is finished
  • Surface scatter
  • Scatter or reflection from non-optical components
    • Tubes, spacers, baffles, physical aperture stop, etc
• Out-of-field sources
  • Direct (oversize of optics)
  • Indirect (Fresnel, scatter)
Limits to the analysis

• Any analysis of stray light is limited by:
  • The ability to properly model scatter from optical and mechanical surfaces
    • Proper measurements of the scatter from all components must be made
      • Almost never the case in “real world”
      • Estimates or generic data useful, but dangerous
  • The accuracy of the computer model
    • Modeling of all necessary optical, mechanical components
    • Tools in software used for the simulation
  • The time available to study the problem
    • Analysis runs take time
    • Analyzing the data takes time
    • An “infinite” number of possibilities exist...
A bit on stray light

• Most of the stray light issues can be found relatively quickly
• Most of the effort is spent looking for what was missed the first time
• Your customers will never be happy:
  • They are not happy if you find any problems:
    • Problems cost money to fix
  • They are not happy if you find no problems:
    • How much time and money did we waste to find nothing?
• There is a certain personal satisfaction a designer gets from knowing more fully that the design will work to the customers expectations (or better)