Camera Calibration Optical Configurations and Calculations

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Objectives

• Efficiently calibrate pixel response over entire camera focal plane to level ~ 0.1%
• Identify ghosting effects
• Model camera optics – ZEMAX

Propose two calibration techniques
1) “Artificial Star” (Scacco and Sonnenfeld)
2) “Headlight” test beam
Optical Deck

- Load standard LSST optical deck
- Consider only the camera
  - Three lenses
  - Filter
  - CCD surface
“Artificial Star” Calculations

Photodiode Array (or Telescope)

Reference Photodiode

Optical Source

14 – 23.6 degrees

L1

L2

Filter

L3

FPA

Reflectivity R ~ 0.3%.
(Not all reflections shown.)

300 μm
(4cm away)

30 μm
(Approximate FWHM of LSST PSF at 0.6 arc-sec seeing.)
Focused pin-hole beam from quartz lamp and monochromator (length of optical source ≈ 1.4m).

Scacco and Sonnenfeld
Methodology

- “Headlight” test beam parallel to optical axis
- Run ZEMAX in non-sequential mode
- L1, L2, and L3
  - Quarter-wavelength magnesium-fluoride AR coating
- CCD treated as reflective surface
  - Scatter fraction = 0.33 \((n = 3.6 \text{ for Si})\)
  - Lambertian angular distribution (scattered intensity is proportional to the cosine of the angle with surface normal)
  - Quarter-wavelength magnesium-fluoride followed by half-wavelength of lanthanum-oxide AR coating

Lambertian scattering
General Strategy

- Scan test beam over pixels in series of exposures
- Each pixel traces out beam intensity profile
- If the spatial profile of the test beam intensity does not change significantly over the characteristic size of the beam at the focal plane, we can compare the response of nearby CCD pixels

What is the optimal test beam size?

How should we scan the test beam?
1 cm Beam Intensity Profile

Test beam intensity profile at focal plane – radial slices

Significant features on 0.1% level

Center of focal plane (0,0) 5 cm offset from center (5cm,0)

Notice rapid change in beam intensity profile!
10 cm Beam Intensity Profile

Test beam intensity profiles at focal plane – radial slices

Intensity profile of larger test beam is more stable

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A Comment on Statistics

Intensity fluctuations readily apparent in 20 minute simulation

Fortunately, we can do much better with a real test beam

Full well potential $\sim 100000$ e$^-$

High QE

Collect $N \sim 40000$ photons in single exposure

$\sigma = \frac{\sqrt{N}}{N} \sim 0.005$

With multiple exposures, can reach 0.1% level accuracy
Center 10 cm diameter beam over a grid of positions

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Test beam positions in cm

Plot incoherent irradiance (W / cm²) on log scale

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Ghosting Analysis

No filter

L1

L2

L3

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Ghosting Analysis

-No filter-

L1+L2  L1+L3  L2+L3
Wavelength Dependence

LSST camera range 400 - 1000 nm
AR coatings are wavelength dependent
Optimize for 700 nm light

400 nm test beam
700 nm test beam
1000 nm test beam

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1. Produce test beam several cm in diameter
2. Scan outwards in radial direction
3. Fit shape of beam intensity profile
4. Scan in concentric circles

Relative calibration possible independent of exact model results

Beam intensity profile changes continuously while going outwards

Take advantage of azimuthal symmetry
Future Directions

• CCD surface most challenging element to model
  – Scoring pattern strongly dependent on CCD surface properties
  – Observe ghosts to understand CCD reflection
• Use ghost patterns to determine relative positions
• Include diffraction in simulations
• Use test beams of various wavelengths to parse QE from pre-amp gain