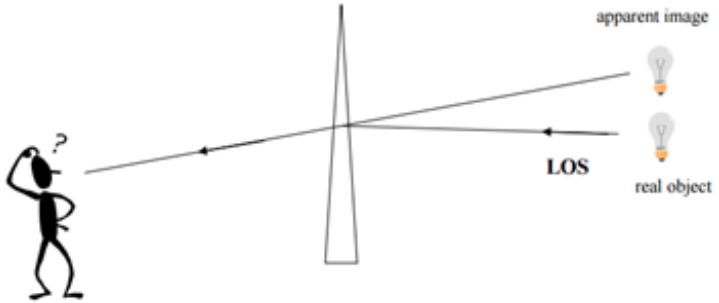
Optical Line of Sight Errors by Small Perturbation

A Tutorial by James Magras

Line of Sight

- LOS defines the central ray or beam line of a system
  - Camera systems (DSLR, GoPro, etc.)
  - Laser systems (metrology, laser cutting, lithography, etc)

- Simply put, LOS determines <u>what we're looking at</u>

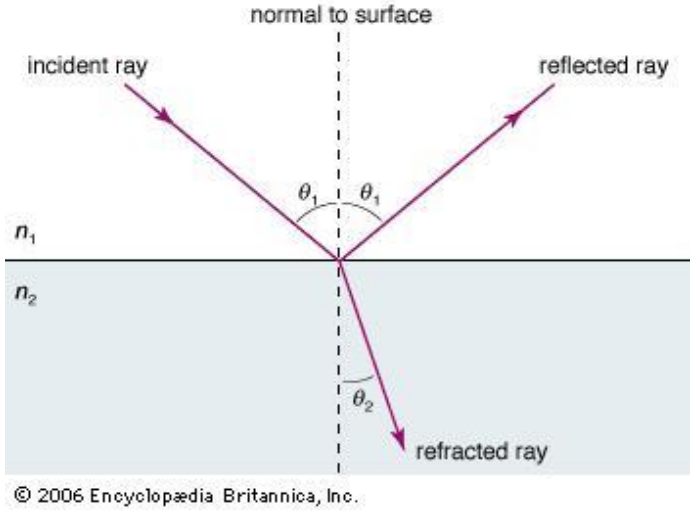


Agenda

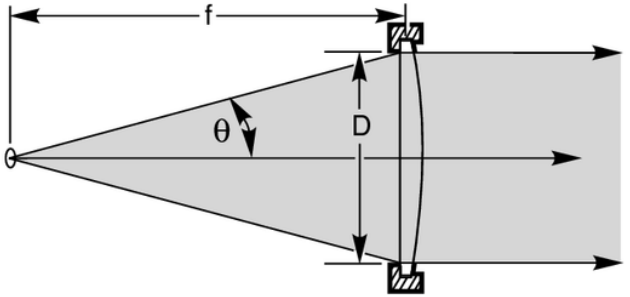
- Optics Primer
- LOS Errors by Component
- LOS Errors, Multi-Component
- Mitigations
- Summary

Optics Primer

- Snell's Law (Refraction)
- Law of Reflection



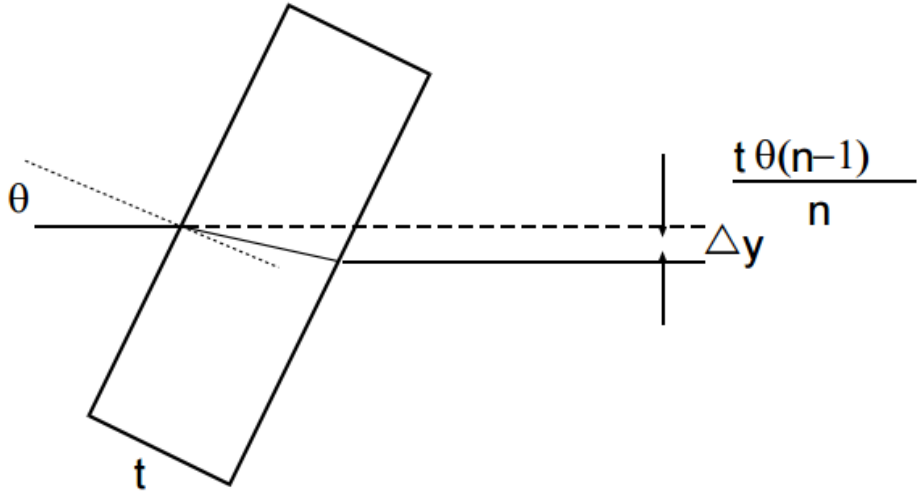
- F/# (F number)
- NA (Numerical Aperture)



$$F\# \approx \frac{f}{D} \qquad N.A. \approx \sin\theta$$

Plane Parallel Plate

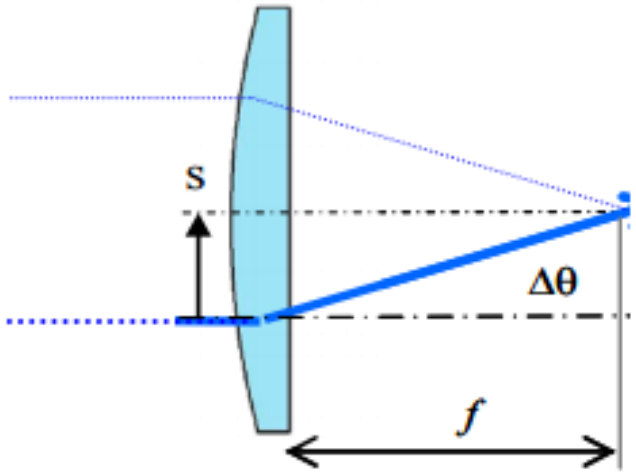
- Solid plate with zero optical power
  - Vacuum windows
  - Beamsplitters



Lens

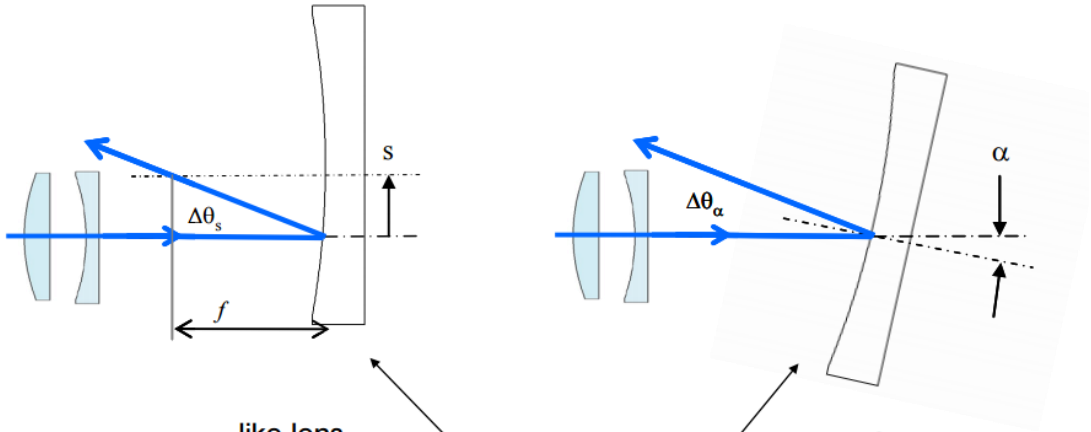
- Transmissive optic
  - Insensitive to tilt
    - 1 degree tilt, 5mm thick BK7 → 30μm deviation
  - Sensitive to decenter

$$\Delta\theta_s \cong \frac{s}{f}$$



Mirrors

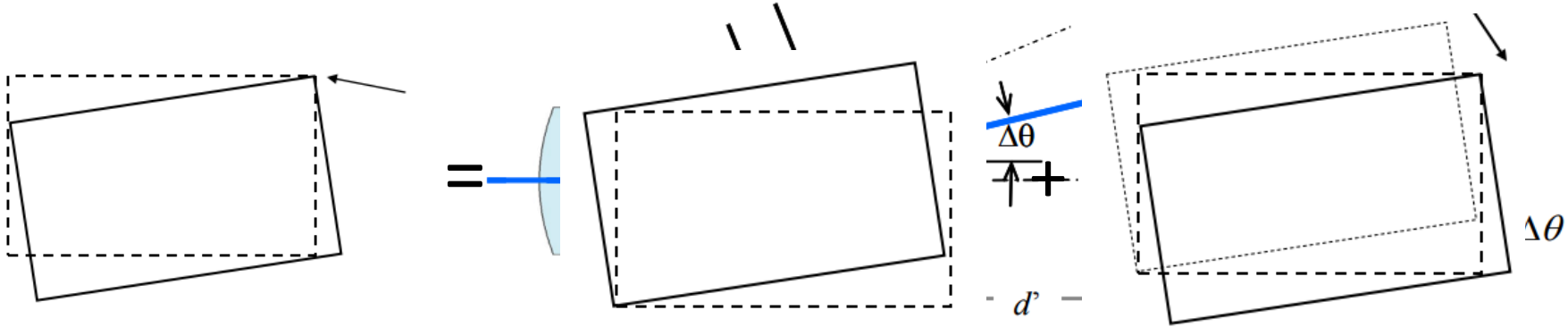
- Reflective substrate
  - Flat: use Law of Reflection
  - Powered: acts like a lens



$$\Delta\theta \cong \frac{s}{f} + 2\alpha$$

BONUS – Tilt About External Point

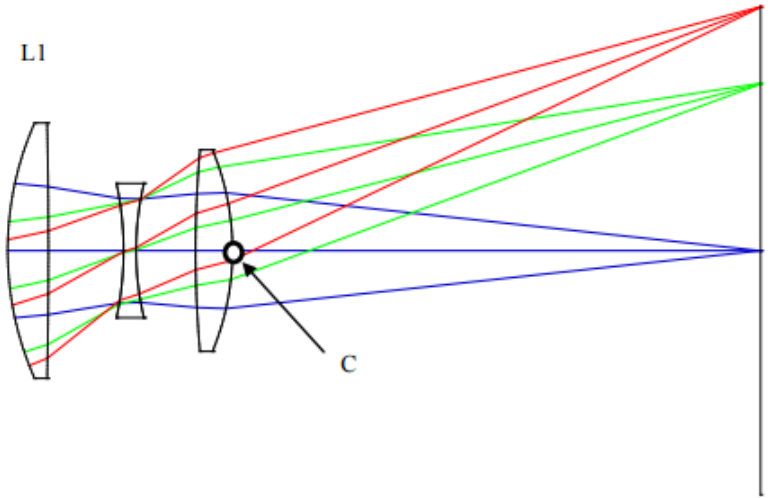
- What happens when an element is tilted about a point external to itself?
  - → Treat the motion as a tilt + decenter



$$CP_{stationary} = -\frac{f}{d'} \cdot PP'$$

System Evaluation

- Calculate effect of single element error on system LOS



$$\varepsilon = \frac{D_i}{2NA}\Delta\theta_i = D_i \cdot F_n \cdot \Delta\theta_i$$

ε	shift in image position
$\Delta\theta_i$	change in ray angle at element i
D_i	beam diameter at element i (looking at rays from on-axis point)
NA	system numerical aperture (defined at image)
F_n	system focal ratio (defined at image)

Use footprint diagram to get D_i, beam footprint on element i for on-axis case

Mitigations for LOS Error

- As always, engineering is a trade-off
  - Tighter tolerances → more expensive
  - Better off-the-shelf mounts → more expensive
  - In-system compensation → more design time
    - Set screws, nudgers, etc.
  - Adhesive position fixing → less flexibility

Summary

- LOS analysis critical to system performance

- Main components
  - Plane Parallel Plate
  - Lens
  - Mirror
- System Error $\varepsilon = F_n D_i \Delta\theta_i$

$$\varepsilon = \frac{t\theta(n-1)}{n}$$

$$\Delta\theta_s \cong \frac{s}{f}$$

$$\Delta\theta \cong \frac{s}{f} + 2\alpha$$

References

- J. H. Burge, “An easy way to relate optical element motion to system pointing stability,” in Current Developments in Lens Design and Optical Engineering VII, Proc. SPIE 6288 (2006).

- Greivenkamp, John E. (2004). *Field Guide to Geometrical Optics*. SPIE Field Guides vol. **FG01**. SPIE. p. 28. ISBN 0-8194-5294-7

- "Light Collection and Systems Throughput." Light Collection and Systems Throughput. Newport Corporation, n.d. Web. 15 Dec. 2015.