ME 297
L6 Line of sight RSS combination

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Ref. Dr. Jim Burge's Notes

LOS optical systems

- **Combining multiple contributions to system LOS**
  - **Independent sources**
  - **Coupled sources**
- **Example problems**
- **General relationship between element motion and system LOS**

Combining multiple independent sources of error

- **Many things that can go wrong that will affect system performance. To calculate the combined effect if:**
  - **Roots of cause independent combine the effects as a Root Sum Square (RSS). Good to know**
    - The answer is dominated by the biggest contributors
    - The smallest contributors are negligible
    - For *N equal contributions, the RSS is equal to square root of N times an individual contribution.*

RSS example

10 μrad pointing from element 1
15 μrad pointing from element 2
5 μrad pointing from element 3

Combined effect:

$$\sqrt{10^2 + 15^2 + 5^2}$$
$$= \sqrt{100 + 225 + 25}$$
$$= \sqrt{350}$$
$$= 18.7$$

RSS is dominated by the largest contributors

Example:

Compute RSS of 10, 1, 2, 1, 1

= sqrt(100+1+4+1+1)

=10.3 (not much different from 10)

Small contributors do not affect RSS

Compute RSS of 10, 11, 10

= sqrt(100+121+100)

= 17.9

Now add another term of 2

rss = sqrt(100+121+100 + 4)

=18.0

Not much different from 17.9

# For terms with equal contribution

Compute RSS for N equal contributions of x:

$$RSS = \sqrt{x^2 + x^2 + x^2 + x^2 + \ldots (N\ times)}$$
$$= \sqrt{N(x^2)}$$
$$= \sqrt{N} \cdot x$$

Few rules for compound systems

- With many independent degrees of freedom the optimal distribution of error may be equal contributions from each DOF.
- System performance can be improved by reducing just the dominant sources of error
- Small contributors can be relaxed to reduce the cost without changing the performance.
- When the performance is good enough, cost of improving in not justified so relax.
- Maximize use of COTS (commercial off the shelf) parts for cost reduction.

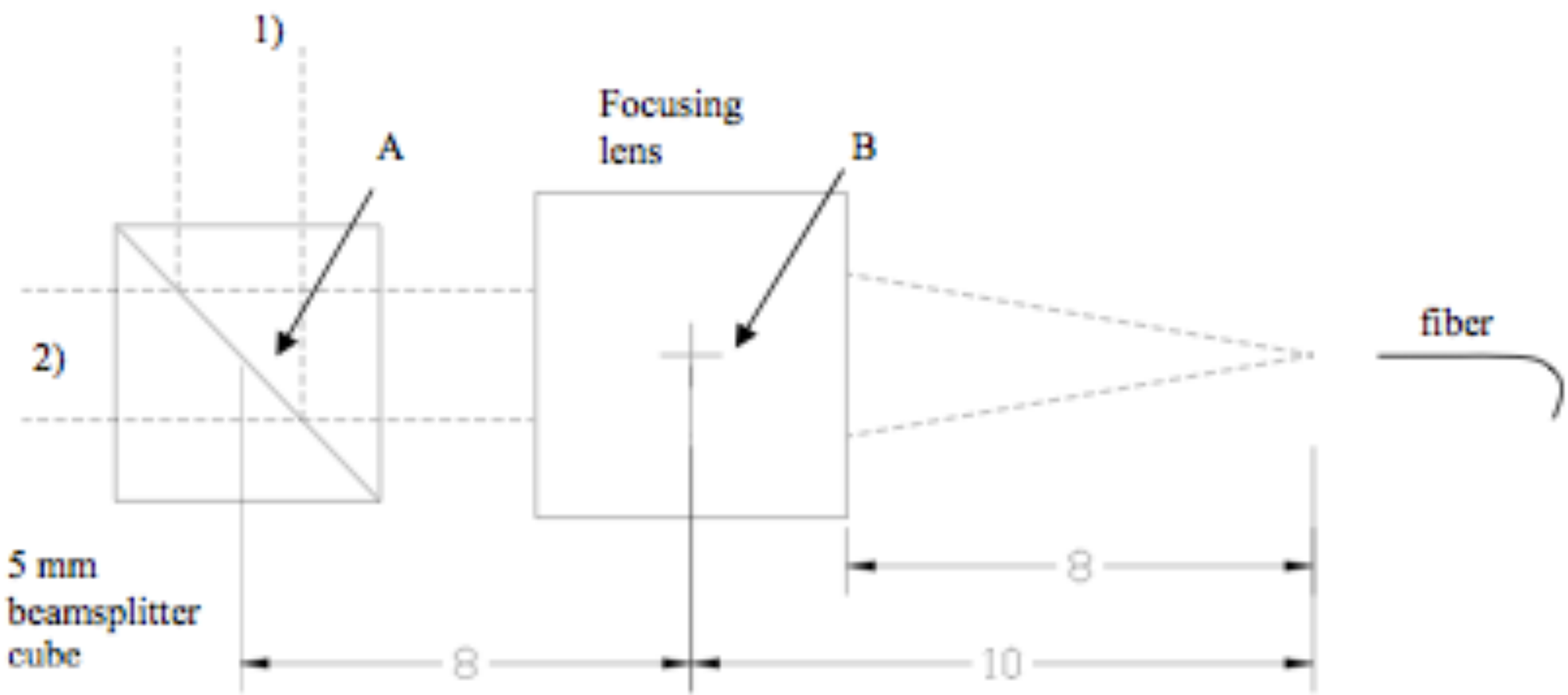
Combining errors when the effects are coupled

- If one root cause results in many changes in the system, then the errors are coupled. For example temperature change causes all the parts expand or contract.
- In these cases the root cause is treated as a degree of freedom (DOF)
- The combined effect for the whole system when the DOF changes is calculated.
- this is done by calculating each contribution and summing them up ***keeping the sign.***

Example Problem : Image stability

- Consider a simple two-channel fiber coupler shown on next page. The incident beams are 3 mm in diameter, and come to focus on the end of the fiber with 0.1 NA. The back focal distance, as shown from the focusing lens (which is a multi-element lens) to the fiber is 8 mm. Coupling efficiency requires the position and rotation of the optics to be maintained so that both focused spots (one from beam 1 and the other from beam 2) are maintained on the fiber to ±0.3 μm

Example Problem : Image stability



Example Problem : Image stability

a) Determine the focal length of the lens and find its nodal point.

Calculate the following sources of error, consider the effects for both inputs 1 and 2

b) Lateral translation of beam splitter cube 20 µm

c) Rotation of the beam splitter cube about point A of 3 µrad

d) Lateral translation of the focusing lens of 0.1 µm

e) Rotation of focusing lens about point B of 20 µrad (decompose motion into rotation about nodal point + translation of nodal point.)

f) Lateral translation of the fiber of 0.1 µm

g) Calculate the combined effect of all of the above and summarize in a table like the one shown

h) How does this compare to the requirement?

Motion	Beam 1	Beam 2	Combined for 2 beams
b)			
c)			
…			
Combined effect			

What happens when an optical element moves

To see image motion,
follow the central ray

Generally, it changes in position and angle

<u>Element motion</u>

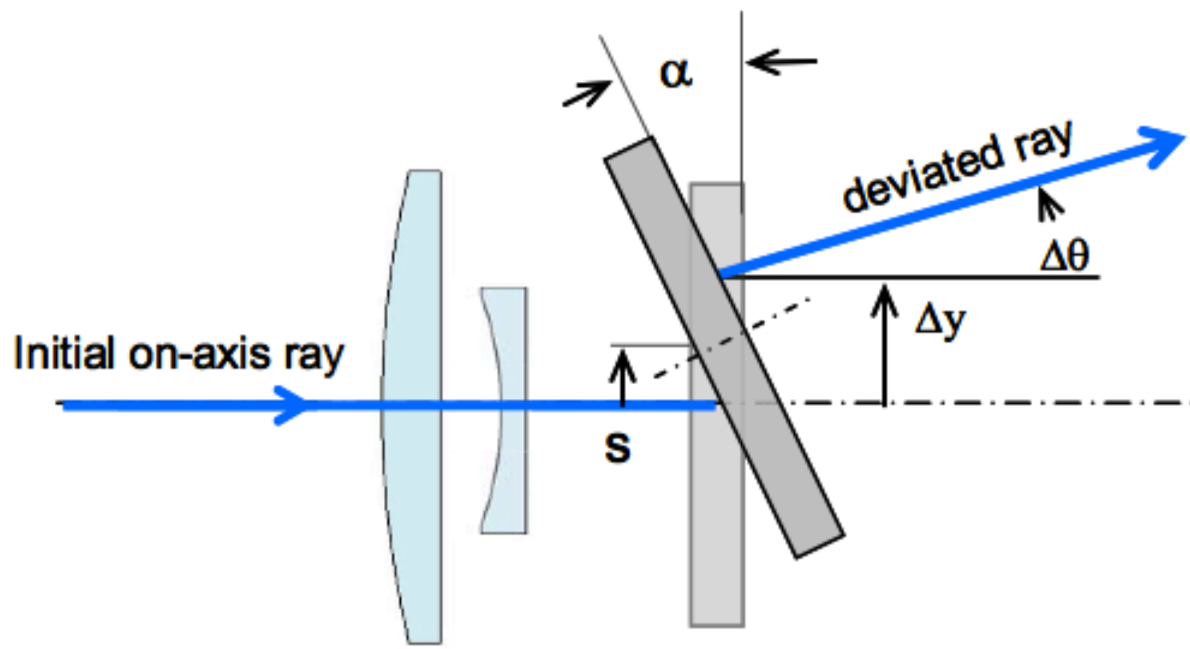
s : decenter

α : tilt

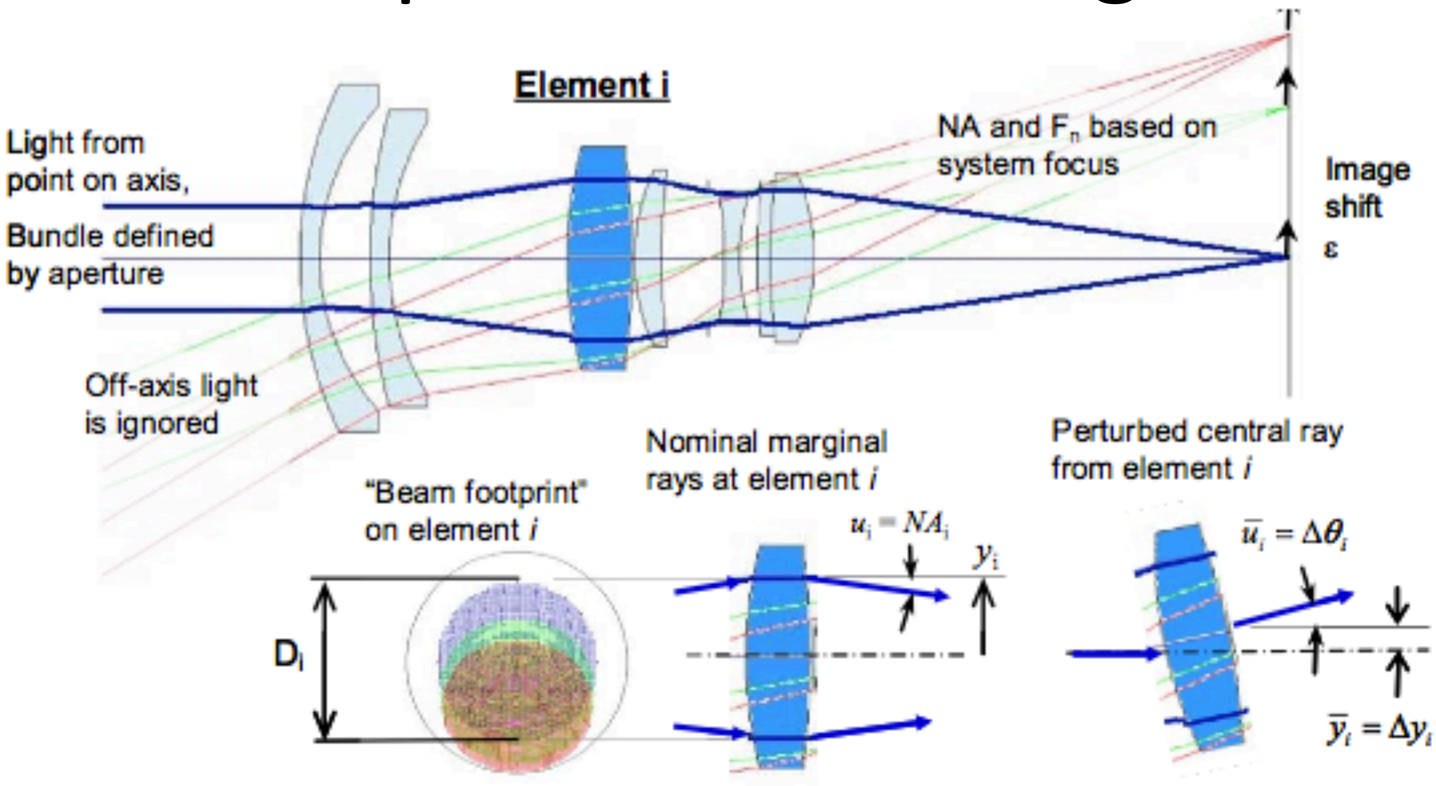
<u>Central ray deviation</u>

Δ*y* : lateral shift

Δθ : change in angle



General expression for image motion



$$\varepsilon = F_n D_i \Delta\theta_i - \frac{NA_i}{NA}\Delta y_i$$

F_n final working f-number = $\frac{1}{2NA}$

D_i beam footprint for on-axis bundle

$\Delta\theta_i$ = change in central ray angle due to motion of element i

General relationship for tilt due to element motion and image shift

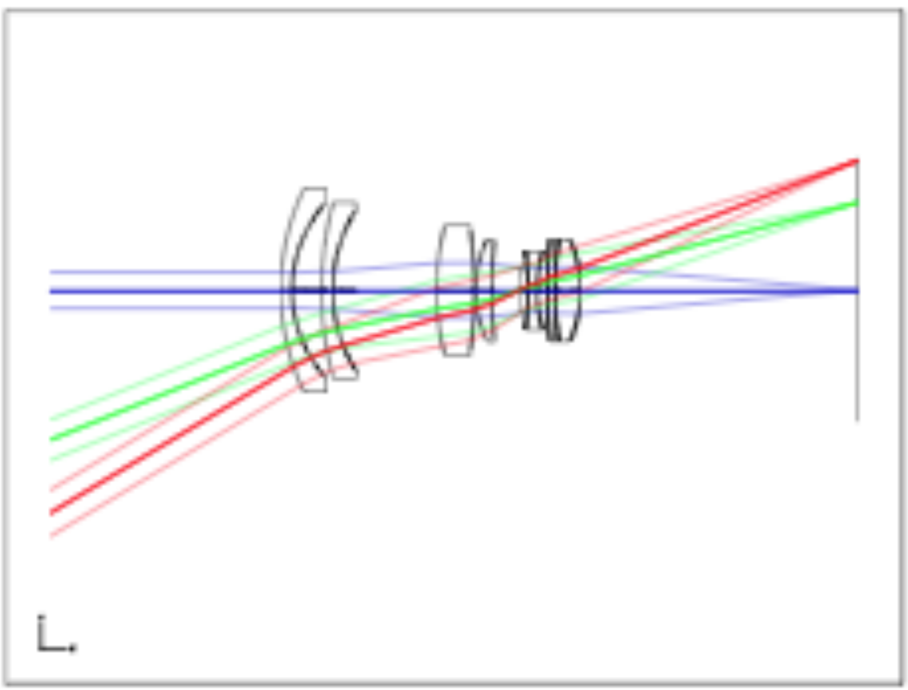
$$\varepsilon = \frac{D_i}{2NA}\Delta\theta_i = D_i \cdot F_n \cdot \Delta\theta_i$$

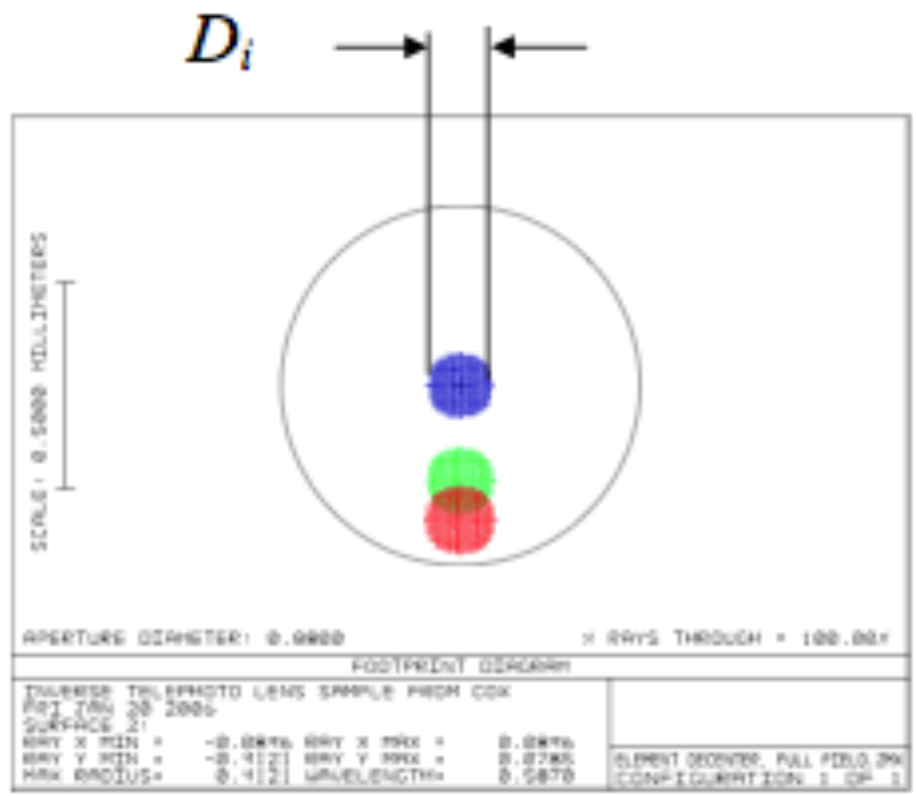
ε	shift in image position
$\Delta\theta_i$	change in ray angle at element *i*
D_i	beam diameter at element *i* (looking at rays from on-axis point)
NA	system numerical aperture (defined at image)
F_n	system focal ratio (defined at image)

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).***

How to find D_i

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





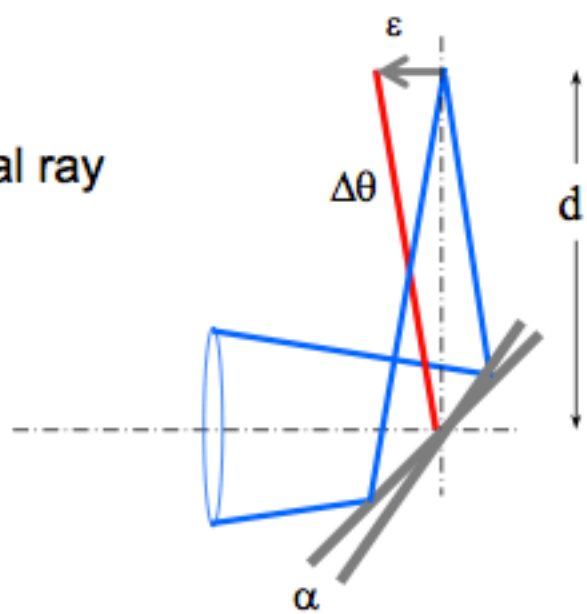
Example for tilt of a mirror

Tilt α causes angular change in central ray $\Delta\theta_i = 2\alpha$

Which causes image motion $\varepsilon = 2F_n D_i \cdot \alpha_i$

"Lever arm" of 2 F_n D_i (obvious for case where mirror is the last element)

Follow the central ray



$$\varepsilon = d\Delta\theta$$
$$= F_n D_i \Delta\theta$$
$$= 2F_n D_i \alpha$$

Small angle approx

D_i is beam size at mirror

This is valid for any mirror!