OPTI 420 – Introductory Optomechanical Engineering

5. Line of Sight - Optical Systems

1. **Combining multiple sources of error**
2. **Calculation of LOS change due to any element motion**
3. **Example problem**

Combining multiple sources of error

There are usually many things that can go wrong that will affect system performance. To calculate the combined effect:

<u>If the causes are independent:</u>
Combine the effects as a root-sum-square

For example:
10 μrad pointing from element 1
15 μrad pointing from element 2
5 μrad pointing from element 3

Combined effect:

$$\sqrt{10^2 + 15^2 + 5^2}$$

$$= \sqrt{100 + 225 + 25}$$

$$= \sqrt{350}$$

$$= 18.7$$

Some interesting things about RSS combination:

1. The answer is dominated by the biggest contributors
2. The smallest contributors are negligible
3. For N equal contributions, the RSS is equal to $\sqrt{N}$ times an individual contribution.

Examples:

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

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

   =10.3   (not much different from 10)

2. 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

3. Compute RSS for *N* equal contributions of *x*:

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

$$= \sqrt{N\left(x^2\right)}$$

$$= \sqrt{N} \cdot x$$

Budgeting complex systems

If you have many degrees of freedom (independent things changing) the optimal distribution may be equal contributions from each thing:

- **If a few terms dominate, you can improve system performance by reducing just them**
- **Any terms that are small compared to the rest could be increased (relax a requirement) to make the system cost less but will not change performance.**

However:

- **Sometimes performance is already good enough, so the cost of improving the dominating single degree of freedom is not justified.**
- **Sometimes the cost will not be reduced by relaxing specifications – *e.g.* using COTS (commercial off the shelf) parts.**

More about this later….

Combining errors when the effects are coupled

For example: Thermal distortion
If the temperature changes then all elements move together.
You cannot estimate the combined effect as a root sum square.

In this case you must treat the single cause of the motion as a degree of freedom. (*e.g.* temperature change)

Then you must find the combined effect for the whole system when the temperature changes.

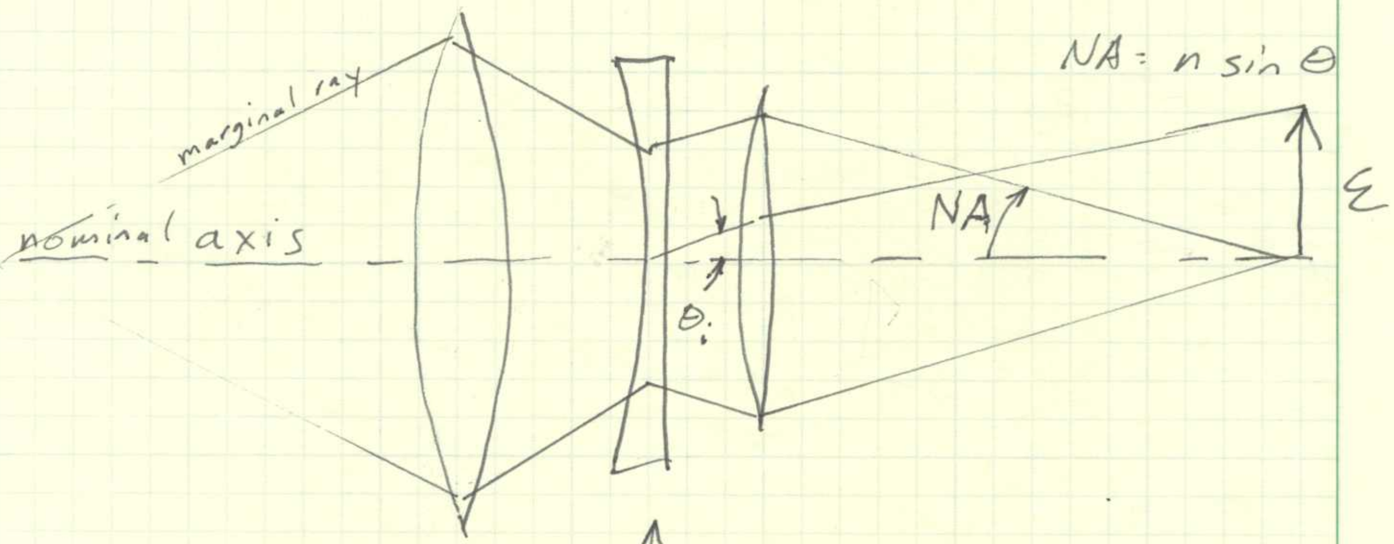
You can do this by calculating each contribution and summing them up ***keeping the sign.***

For example, consider two lenses. The effects of the individual motions could act in a direction to cancel each other or to add.

Clearly a different result.

Multi-element systems - LOS

Calculate the change in system line of sight from motion of a single element



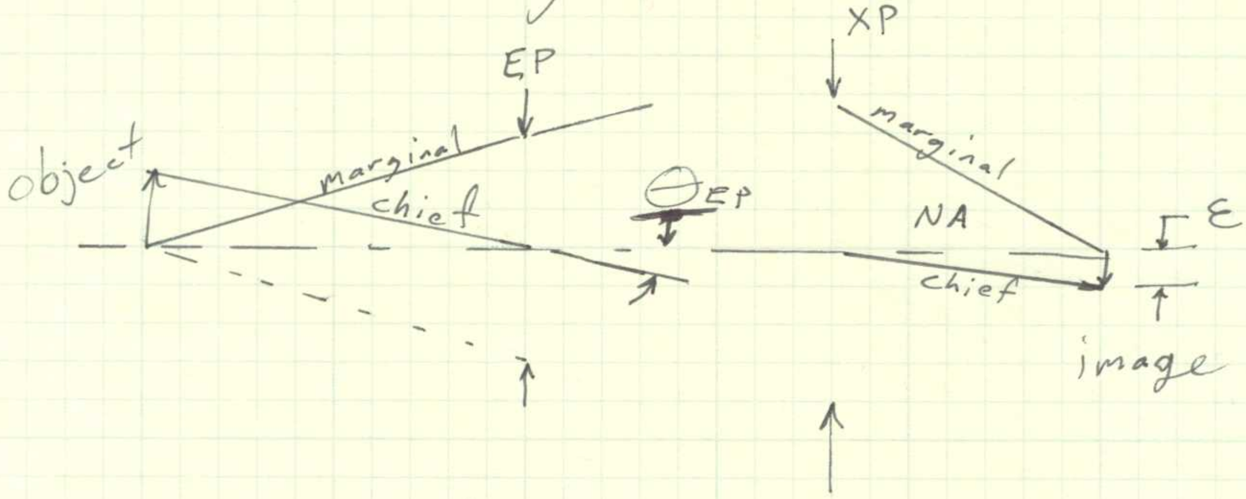
Optical Element i

D_i = Diameter of beamprint on i

$\Delta\Theta_i$ = Deviation of central ray

$$\varepsilon = \frac{D_i \Delta\Theta_i}{2\,NA}$$

La Grange Invariant



$$\mathcal{H} = n\bar{u}y - nu\bar{y}$$

$\bar{y}, \bar{u}$ = chief ray height, angle

y, u = marginal ray height, angle

D_{EP} = Diameter of EP

At EP: $\bar{y} = 0$ $\quad \mathcal{H} = n_{EP}\bar{u}y = \frac{D_{EP}}{2}\theta_{EP}$

at image $y = 0$ $\quad \mathcal{H} = -n_{image}u\bar{y} = NA \cdot \varepsilon$

(in air, taking only magnitude)

$$\frac{D_{EP}}{2} \cdot \theta_{EP} = NA \cdot \varepsilon$$

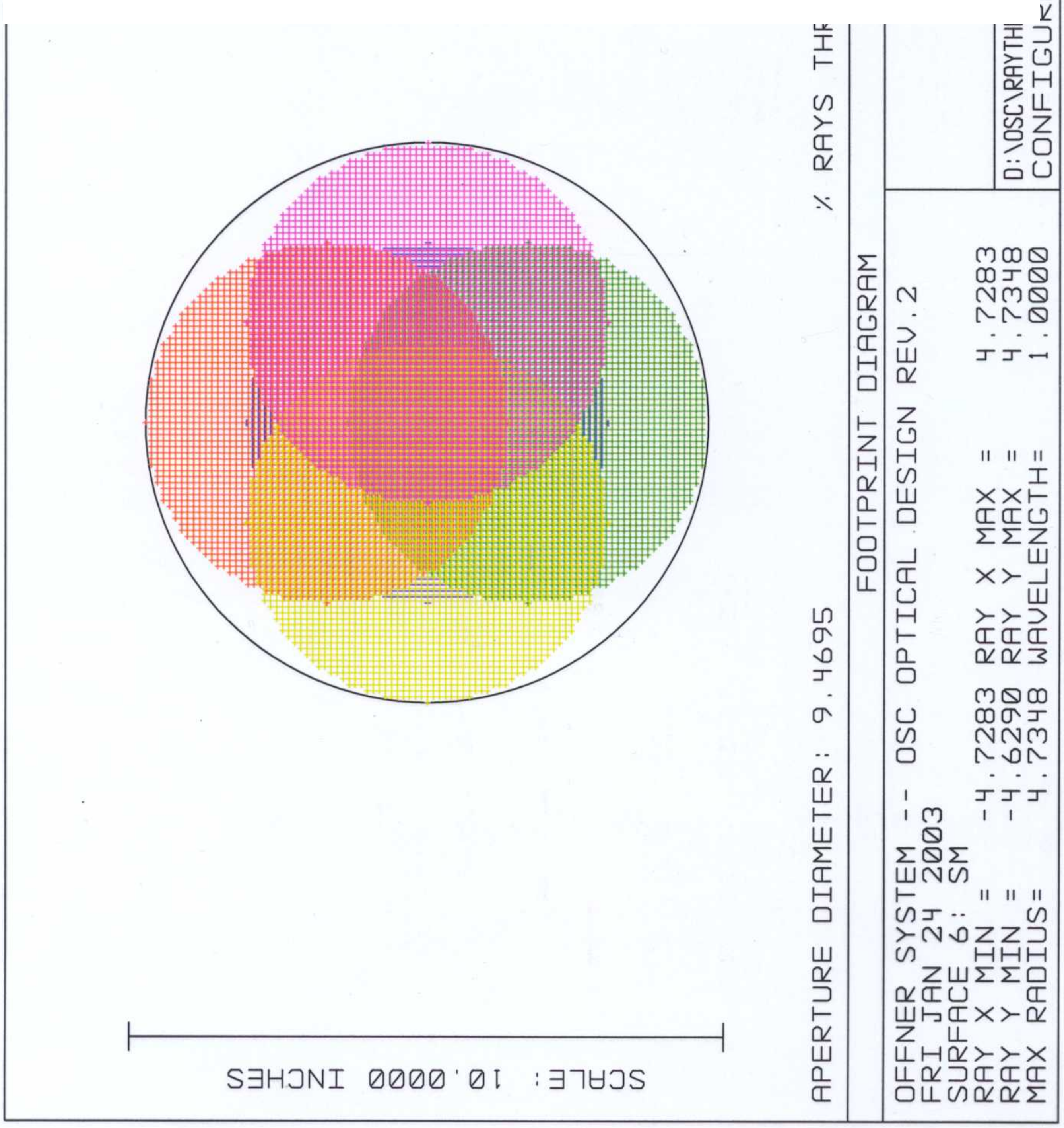
$$\varepsilon = \frac{D_{EP}\theta_{EP}}{2NA}$$

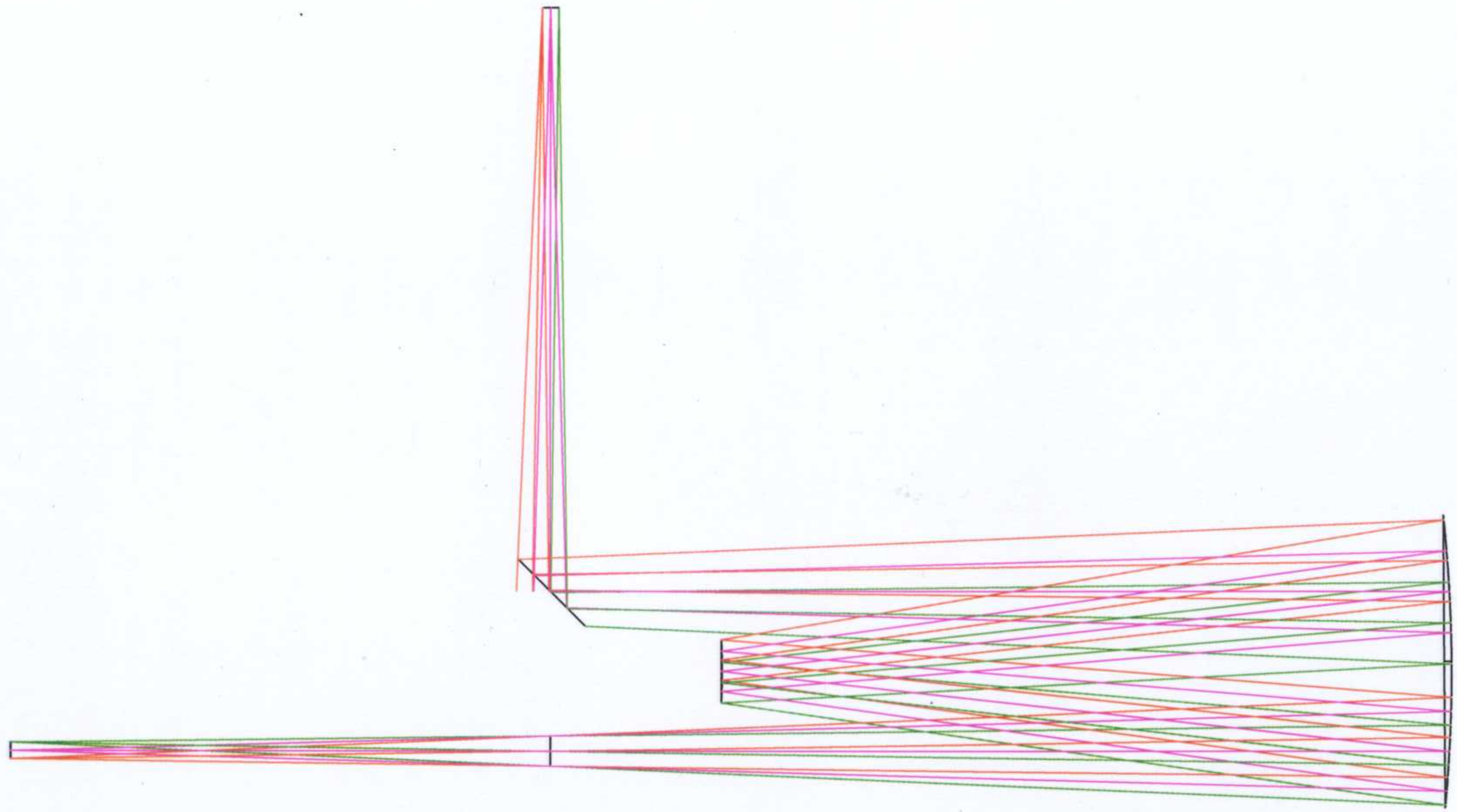
There is no magic about the choice of stop for this!

Evaluate the system as if the stop was located at the surface of interest

$$\varepsilon = \frac{D_i \Delta\Theta_i}{2NA}$$

Get beam footprint by "footprint diagram" in Zemax, CodeV calculate using first order optic.





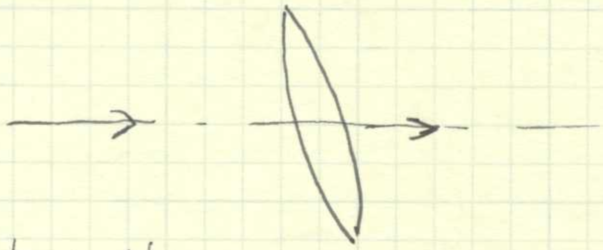
3D LAYOUT

OFFNER SYSTEM -- OSC OPTICAL DESIGN REV.2
FRI JAN 24 2003

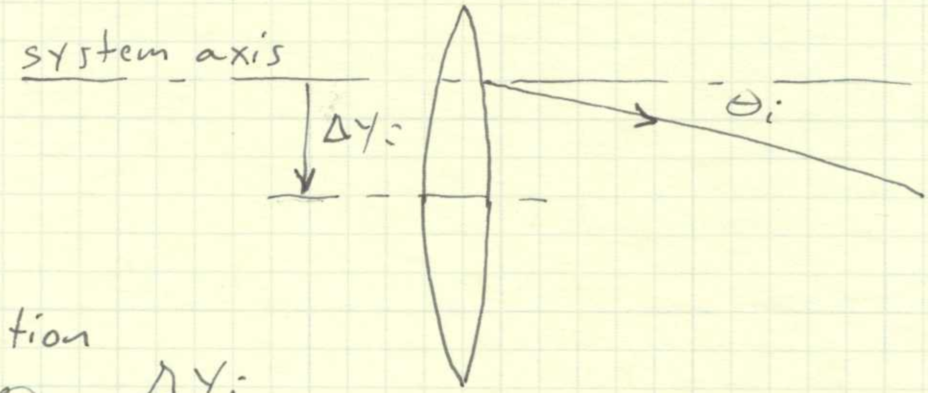
D:\OSC\RAYTHEON\OPTICAL\110902A.ZMX
CONFIGURATION 1 OF 1

Calculation of $\Delta\theta_i$

Lens:



Tilt: No Effect



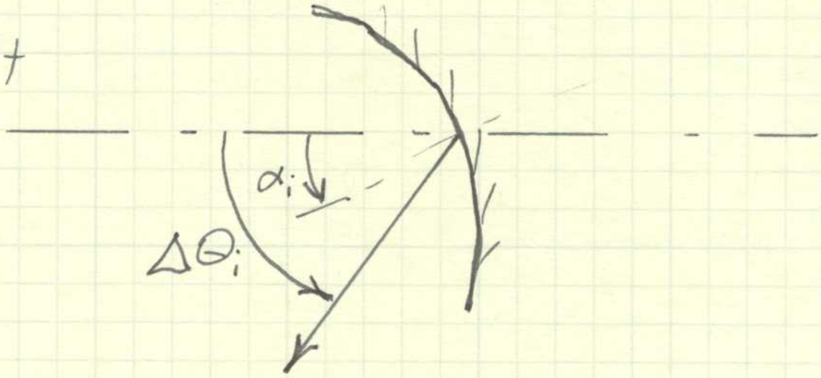
Translation

$$\theta_i = \frac{\Delta Y_i}{f_i}$$

$$= \Delta Y_i \cdot \phi_i = \Delta Y_i \cdot \left(\frac{n-1}{R_1} + \frac{1-n}{R_2} \right)$$

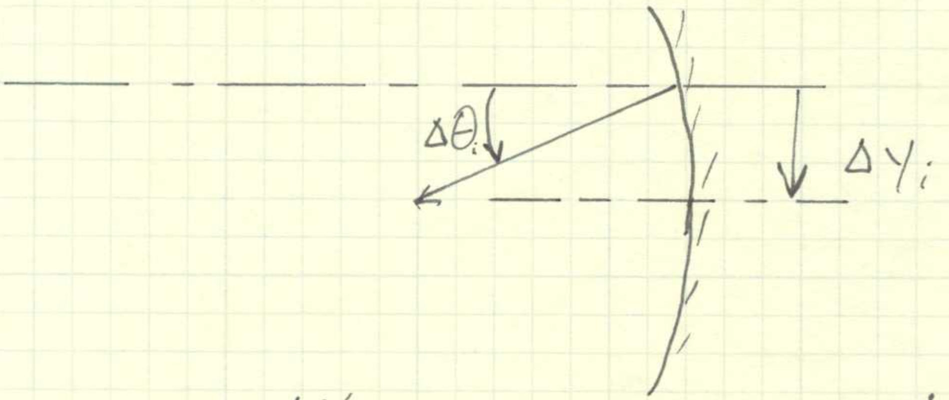
Calculation of $\Delta\Theta_i$

Mirror Tilt



$$\Delta\Theta_i = 2 \cdot \alpha_i$$

Translation:



$$\Delta\Theta_i = \frac{\Delta Y_i}{f_i} = \Delta Y \, \phi_i = \Delta Y \left(\frac{2}{R_i}\right)$$

(same as lens)

So:

For each element:

Determine Beamprint (size of on-axis beam) : D_i

Determine change in slope for axial ray : $\Delta\theta_i$

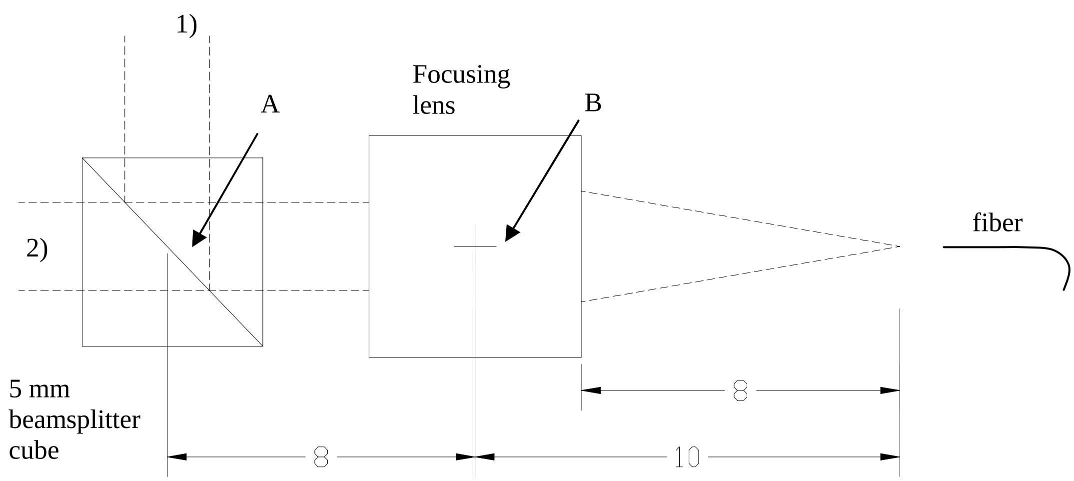
$$\varepsilon_i = \frac{D_i \, \Delta\theta_i}{2\,NA}$$

No. 5505 Engineer's Computation Pad

Example Problem Image stability

Consider a simple two-channel fiber coupler shown below.

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 A and the other from B) are maintained on the fiber to ±0.3 μm



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 beamsplitter cube 20 μm
C) Rotation of the beamsplitter 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. How does this compare to the requirement?

A) NA = 0.1 so it is f/5 (NA = $1/(2F_n)$)

3 mm beam diameter

Focal length f = F_n * D = 3 mm * 5 = 15 mm

Nodal point is 15 mm in front of focus, 5 mm in front of B

B) translation of beamsplitter does not change angle of beam – no effect

C) Rotation of beamsplitter by 3 μrad:

   a. Reflected beam #1, light deviates by 2 * 3 μrad = 6 μrad
      spot motion of EFL* α = 15 mm * 6 urad = 90 μ(mm)
      = 90 nm = 0.090 μm

   b. Transmitted beam #2 – no effect

D) Lateral translation of lens by 0.1 μm causes image to move by 0.1 μm

E) 20 μrad Rotation about B moves nodal point by 20 μrad* 5 mm = 100 μ(mm) = 0.1 μm

F) 0.1 μm Lateral translation of fiber looks the same as 0.1 μm image motion

G) Combine in RSS

	Beam #1 (μm)	**Beam #2 (μm)**
B	0	0
C	0.09	0
D	0.1	0.1
E	0.1	0.1
F	0.1	0.1
RSS	**0.2** (actually 0.195)	**0.17**