

Basic Optics and Optical System Specifications

Prof. Jyh-Long Chern
IEO, NCTU

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jlchern@faculty.nctu.edu.tw
osdman@hotmail.com

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- *Homework 2: Progressive addition lens*

Textbook:

***Robert E. Fischer, Biljana Tadic-Galeb, Paul R. Yoder
Optical System Design 2nd, ed. (SPIE Press, 2008)***

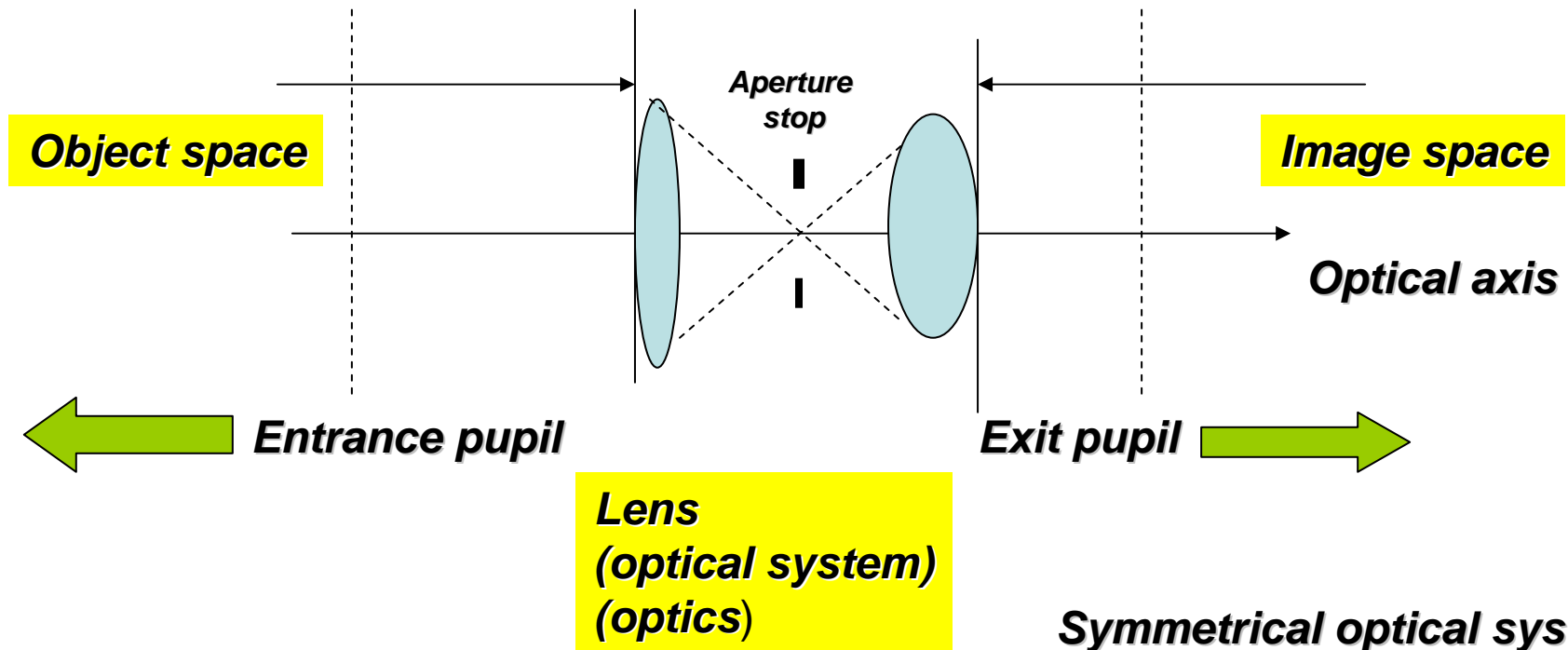
Chapter 1

The purpose of an imaging optical system

Schematic layout of an optical system

Physical (real front/rear objects)

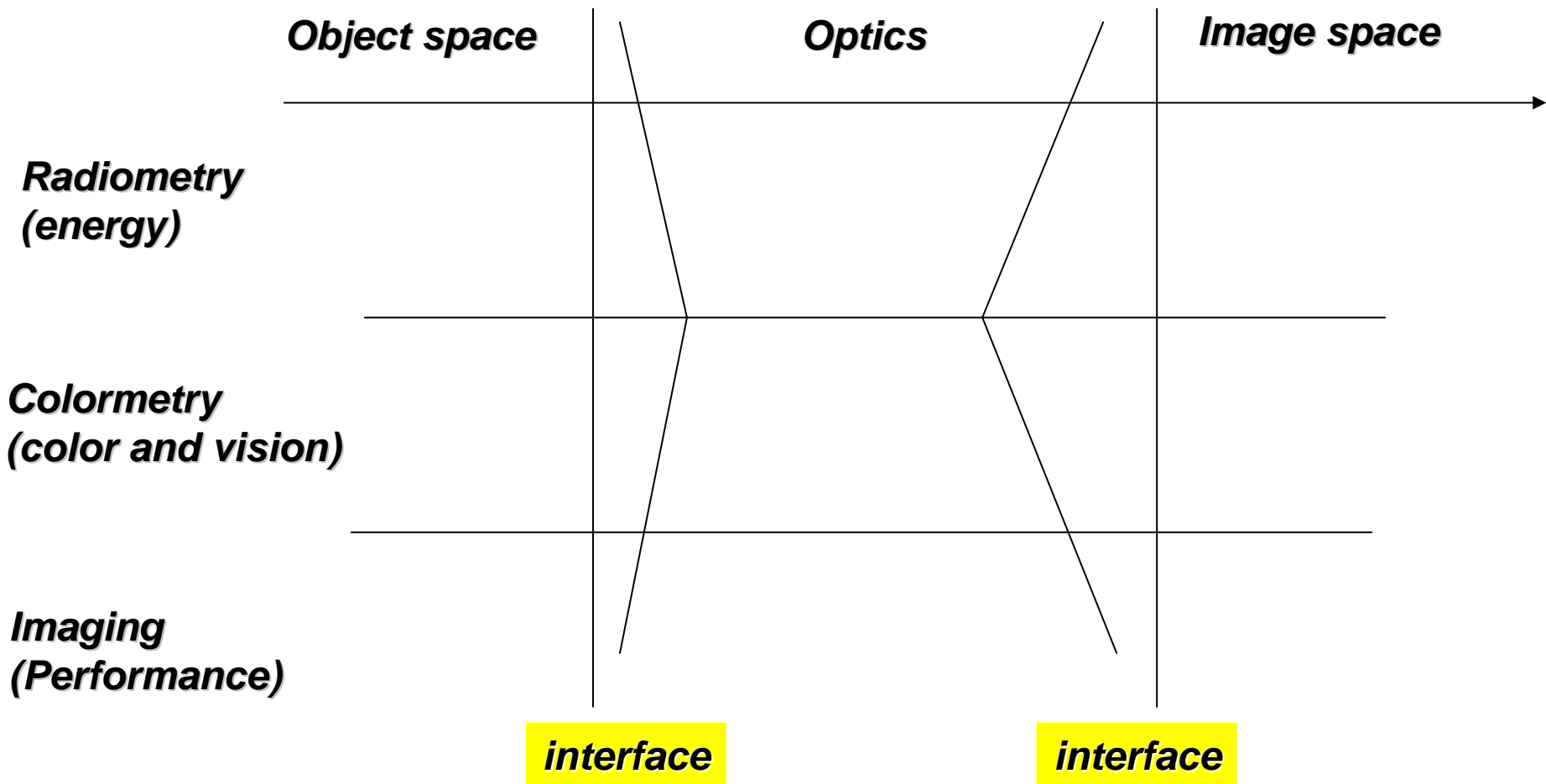
Optical (entrance/exit pupils)



Excel summary

<i>Purposes of imaging optical system</i>				
	issue	lens implementation	key performance evaluation	Remarks
1	object magnification	1. magnifier 2. enlarging system	less distortion	magnification ratio glass or plastics
2	object imaging to sensor	1. camera lens 2. digital video (DV)	high MTF high relative illumination high illumination short TTL	chief ray angle CCD/CMOS Wafer-level optics (VGA/MP)
3	object projection to screen	1. projection lens	throughput optimized high MTF tolerance to depth of field/focus	LED illumination DLP/LC on chip
4	Scanning / identification	1. scanner (laser) 2. optical mouse	dynamical range speckle recognition depth of field/focus	laser or LED IR post-processing
5	relay the image	1. relay lens 2. relay system	less distortion magnification control pupil matching	
6	multifunction	1. zoom lenses	easy to implement	free-form asymmetrical
7	concretion to human eye	progressive (addition) lens	image recovery	
8	enhance visual capability	1. head-up display 2. binocular	image retrieval	military applications

How to specify your optical system: Basic Parameters



Excel summary

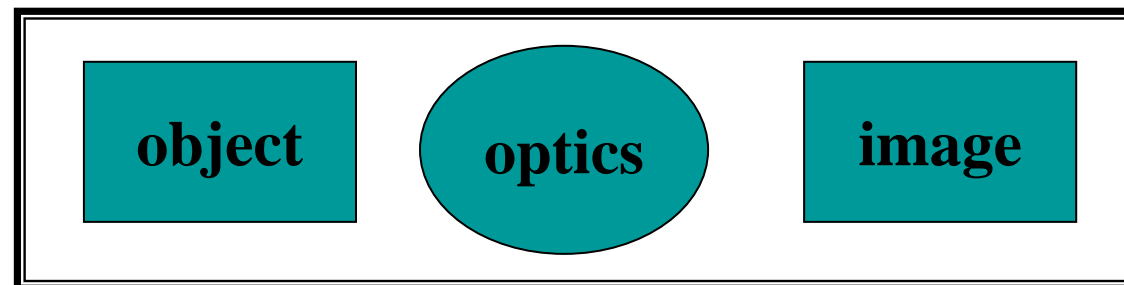
Specifications

1. Target
2. Work flow
3. Datasheet
4. Prototype
5. Sample run
6. Mass production
7. Product (End of Life)

<i>How to specify your optical system specification</i>		
category	issue	remarks
flow		
1	system identification	
	1.1 application	
	1.2 dimension of optical system	
	1.3 identification of object space	
	1.4 identification of image space	
2	engineering specification	
3	design and review	
4	prototyping and review	
5	Integration and assembly procedure	
6	testing procedure	
7	quick identification and review	
datasheet		
1	specification	
	1.1 throughput	
	1.2 resolution (MTF) propagation	
	1.3 physical dimension specification	
	1.4 Pupil location identification	
	1.5 characteristic ray tracing specification	
2	Assembly procedure	
3	testing procedure	
4	quick identification	

Full list of specifications

category	#	item	Remarks
	1	Basic System Parameters	
	2	Optical Performance	
	3	Lens System	
	4	Sensor	
	5	Packaging	
	6	Environment	
	7	Illumination	
	8	Radiometry Issue, source	
	9	Radiometry Issue, Image	
	10	Schedule and Cost	



1. Basic system parameters

1. *You need to have the data of first-order optics*
2. *Clarify the roles of sources and image (detector) plane*
3. *Identify the needs, i.e., what is your application?*

Basic System Parameters					
category	#	item	remarks	operand	limitation
	1	Application identification			
	2	object distance			
	3	image distance			
	4	object to image total track			
	5	focal length			
	6	f/number (or numerical aperture)			
	7	Entrance pupil diameter			
	8	Entrance pupil location			
	9	Exit pupil diameter			
	10	Exit pupil location			
	11	wavelength band			
	12	wavelengths and weight for 3 or 5 λ s			
	13	full field of view			
	14	object height (form and size)			
	15	magnification			
	16	zoom ratio (if zoom system)			
	17	image surface size and shape			
	18	detector type			

2. Optical performance

1. *Throughput (energy)*
2. *Quality characterization*
 - *Spot size and form/MTF;*
 - *Distortion;*
 - *Field curvature*
 - *Astigmatism*

Optical Performance					
category	#	item	remark	operand	limitation
	1	Transmission			
	2	Relative illumination (vignetting)			
	3	Encircled energy			
	4	MTF as a function of line pairs/mm			
	5	distortion			
	6	Field curvature			
	7	astigmatism			
	8	chief ray angle			
	9	depth of field			
	10	depth of focus			

3. Lens system

1. *Materials and coating (database)*
2. *Fabrication available*
3. *Technology available*

Lens system					
category	#	item	remark	operand	limitation
	1	Number of elements			
	2	location of aperture stop			
	3	Glass versus plastics			
	4	aspheric surfaces			
	5	diffractive surfaces			
	6	coatings			
	7	cover glass			
	8	IR-cut glass			
	9	pupil matching			
	10	compensator (lens)			

4. Sensor

1. *Response curve*
2. *S/N estimate*
3. *Limitation of MTF/Spot size*
4. *Color requirement*

Sensor					
category	#	item	remark	operand	limitation
	1	sensor type			
	2	full diagonal			
	3	number of pixels (vertical)			
	4	number of pixels (horizontal)			
	5	pixel pitch (vertical)			
	6	pixel pitch (horizontal)			
	7	Nyquist frequency at sensor, line pairs/mm			

5. Packaging

1. *Tolerance range*
2. *How to implement testing together?*
3. *Including “Compensator design”*

Packaging					
category	#	item	remark	operand	limitation
	1	object to image total track			
	2	entrance pupil location			
	3	entrance pupil size			
	4	exit pupil location			
	5	exit pupil size			
	6	back focal distance			
	7	maximum diameter			
	8	maximum length			
	9	weight			

6. Environment

1. *Irreversible? (damage forever?!)*
2. *Dynamical range*

Environment					
category	#	item	remark	operand	limitation
	1	thermal soak range to perform over			
	2	thermal soak ange to survive over			
	3	vibration			
	4	shock			
	5	condensation			
	6	humidity			
	7	sealing			

7. Illumination

1. *Coherence*
2. *Polarization*
3. *Spatial distribution*
4. *Temporal characteristics*

Illumination					
category	#	item	remark	operand	limitation
	1	source type			
	2	power, in watts			

8. Radiometry issue (source)

1. *Is the distance long enough such that the uses of common radiometry and photometry are safe and proper?*
2. *Are the datasheets enough?*

Radiometry (source)					
category	#	item	remark	operand	limitation
	1	relative illumination			
	2	illumination method			
	3	veiling glare and ghost images			

9. Radiometry issue (Image)

1. *Is the distance long enough such that the uses of common radiometry and photometry are safe and proper?*
2. *Are the datasheets enough?*

Radiometry (image)					
category	#	item	remark	operand	limitation
	1	Transmission			
	2	relative illumination			
	3	stray light attenuation			

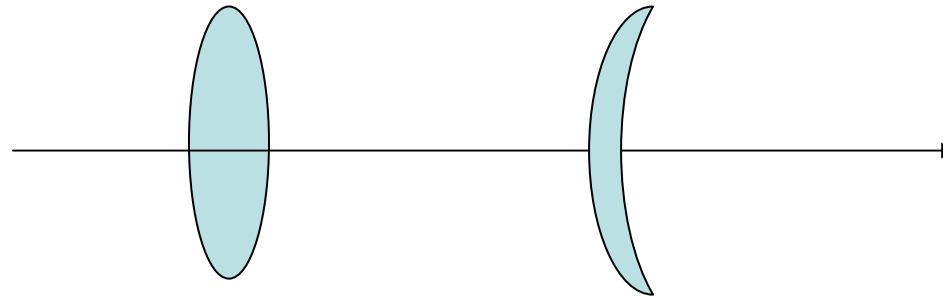
10. Schedule and Cost

*Manager's responsibility
Database available?*

Schedule and cost					
category	#	item	remark	operand	limitation
	1	number of system required			
	2	initial delivery date			
	3	target cost goal			

Basic definition of terms (1)

Paraxial optics



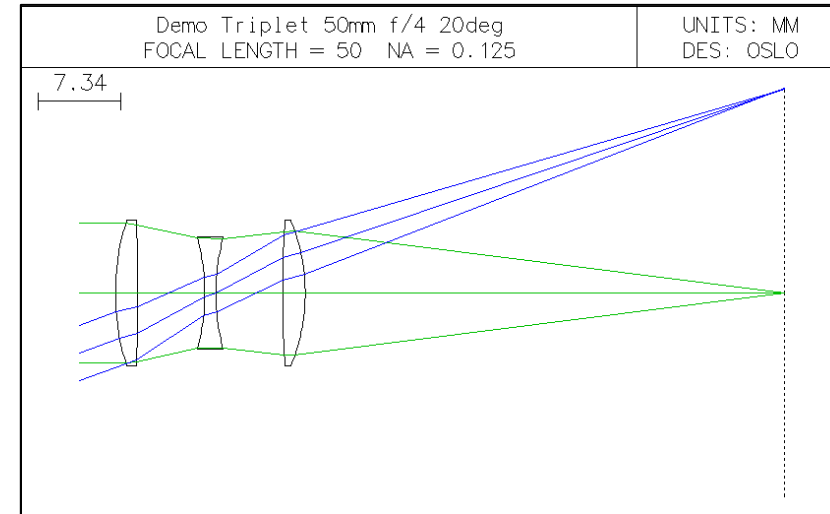
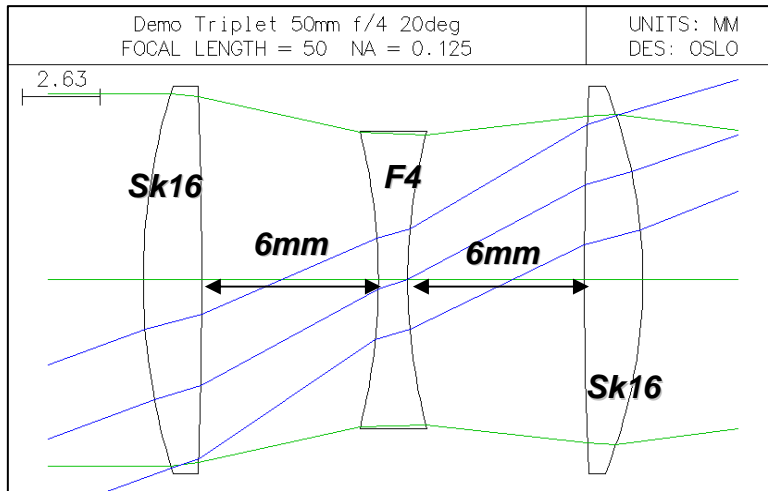
Small angle approximation
Thin lens approximation



**Positive
power**

**Negative
Power**

Illustration: thick lens and thin lens



	Thick lens		Thin lens
	Optical power	efl	Perfect lens (efl)
1	0.33	30.33	30.33
2	-0.06	-15.87	-15.87
3	0.04	24.93	24.93
total	0.02	50.00	48.02

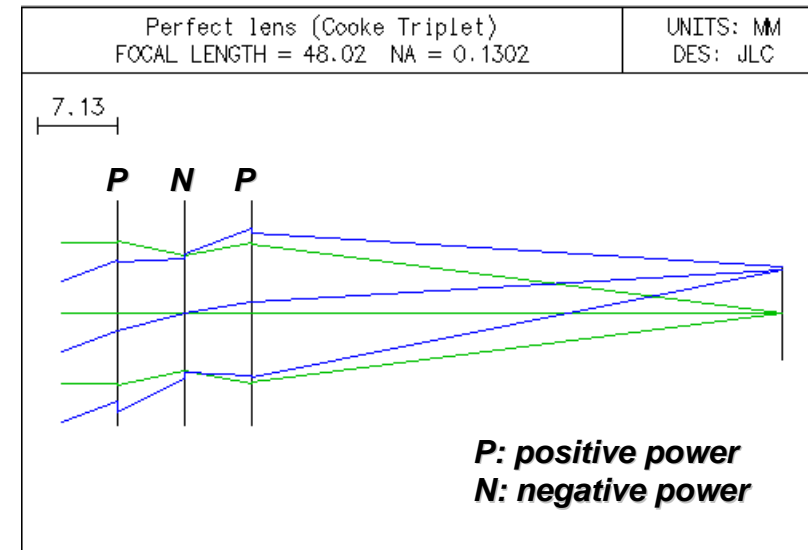
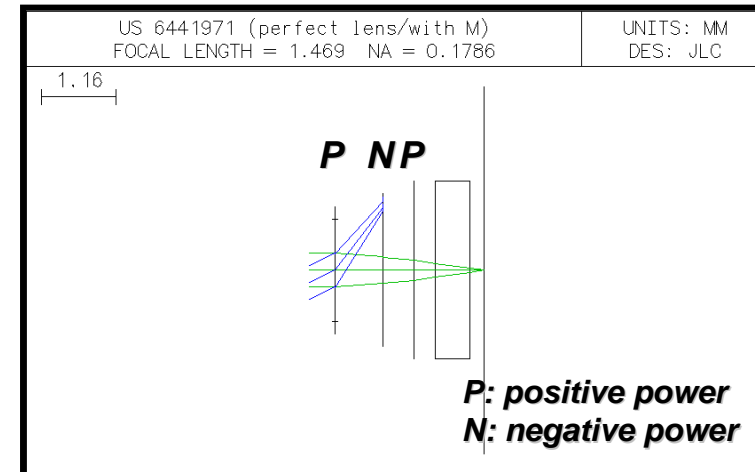
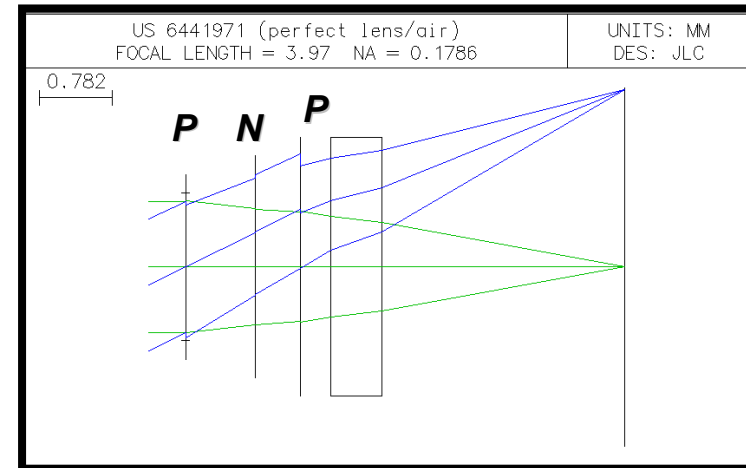
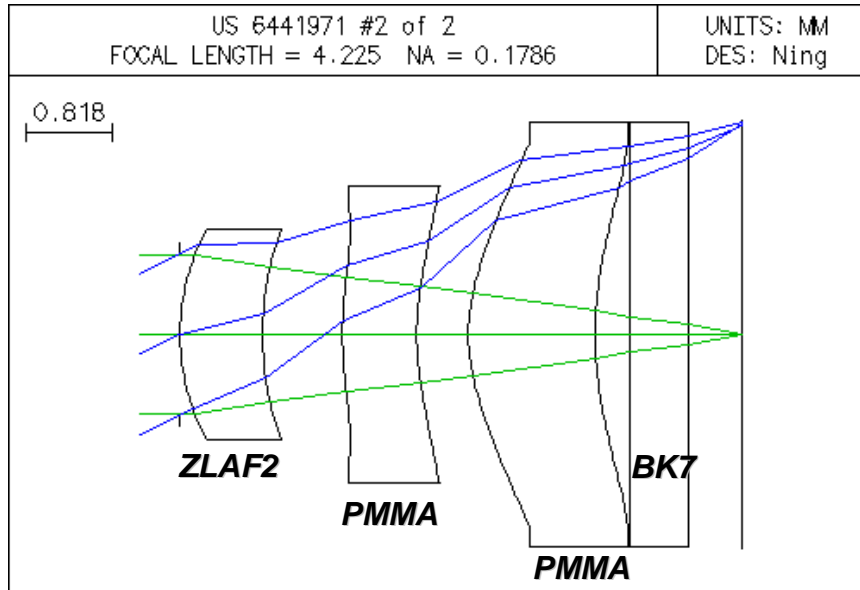


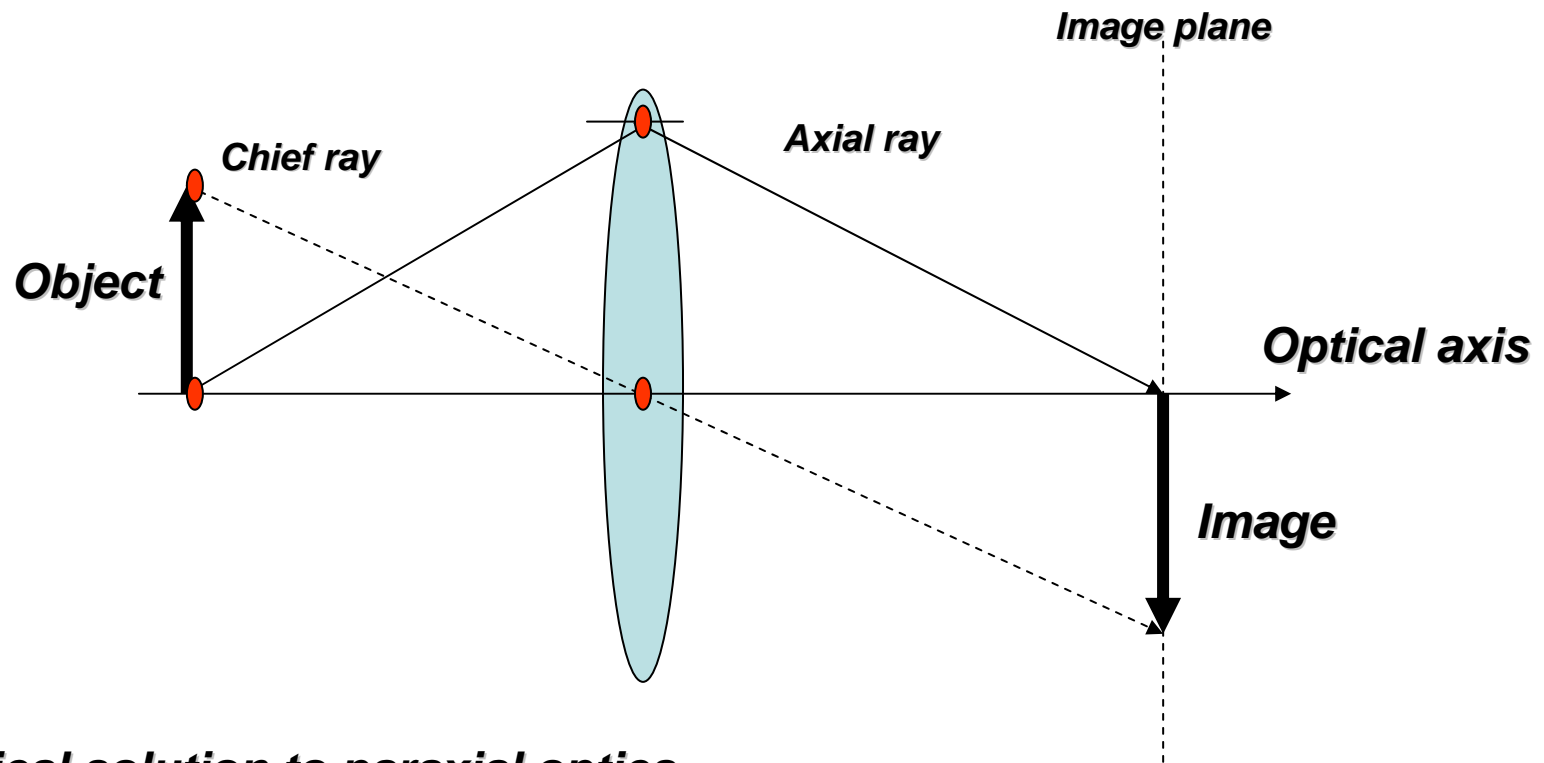
Illustration: thick lens and thin lens



	Thick lens		Thin lens	
	Optical power	efl	Perfect lens Air lens (efl)	Materials lens (efl)
1	0.159	6.307	6.307	6.307
2	-0.078	-12.852	-12.852	-12.852
3	0.193	5.170	5.170	5.170
4	0	0	0	0
total	0.237	4.225	3.970	1.469

Basic definitions of terms (2)

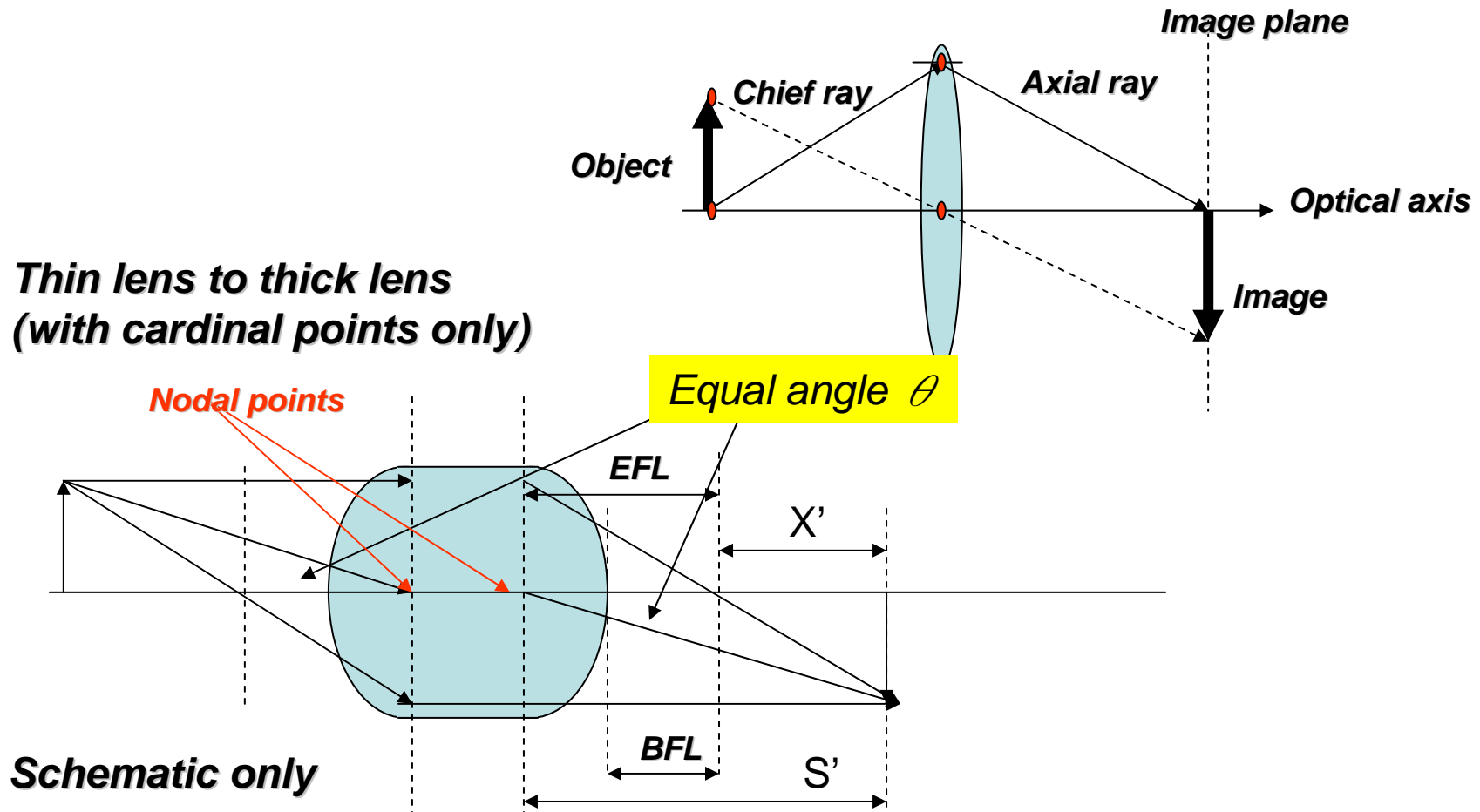
Optical axis, chief ray (principal ray) and axial ray (marginal ray)



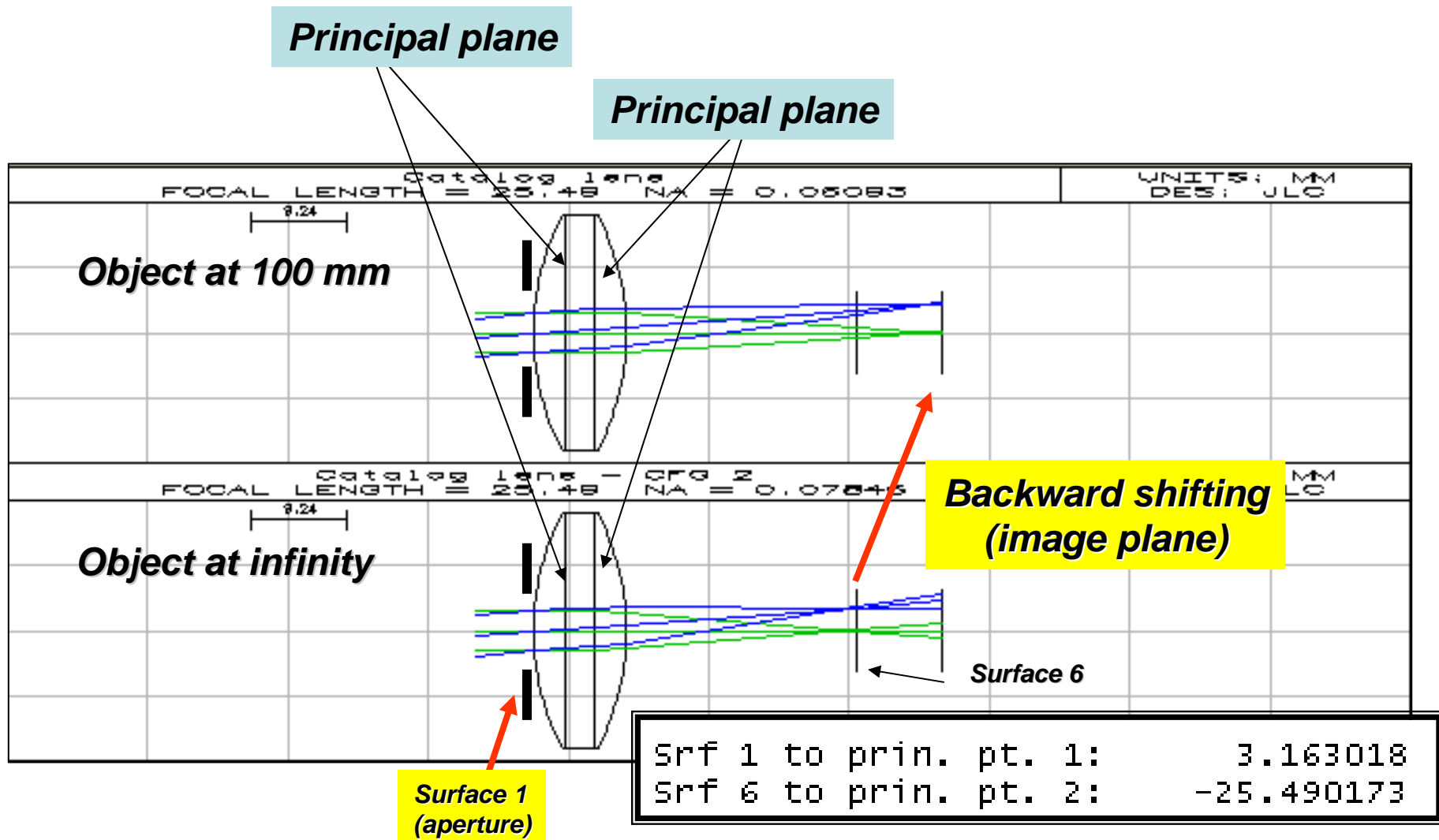
**Geometrical solution to paraxial optics
(with chief ray and axial ray only)**

Basic definitions of terms (3)

Cardinal points of an optical system



Numerical illustration



Useful first-order relationship (1)

Finite conjugate system

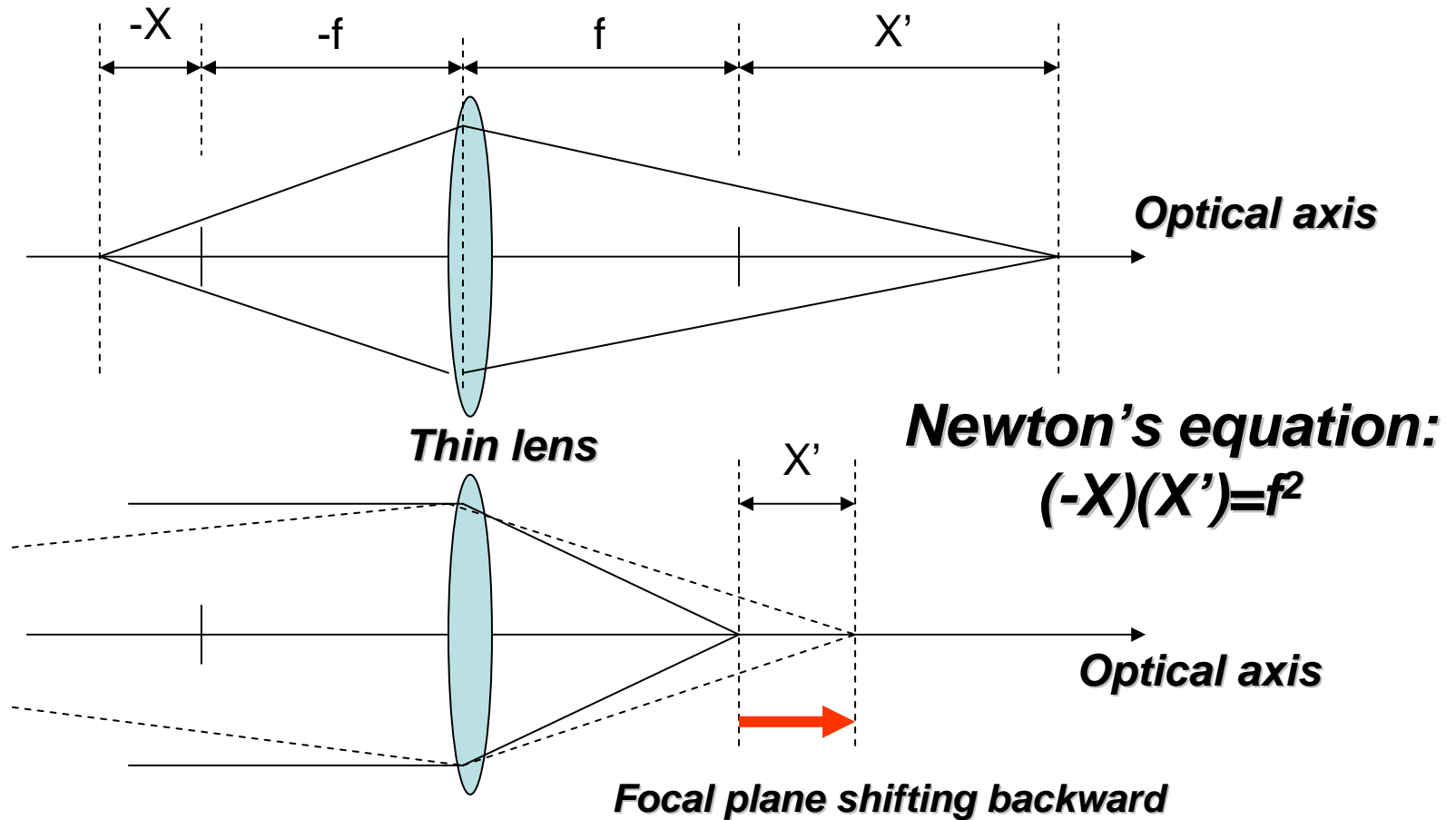
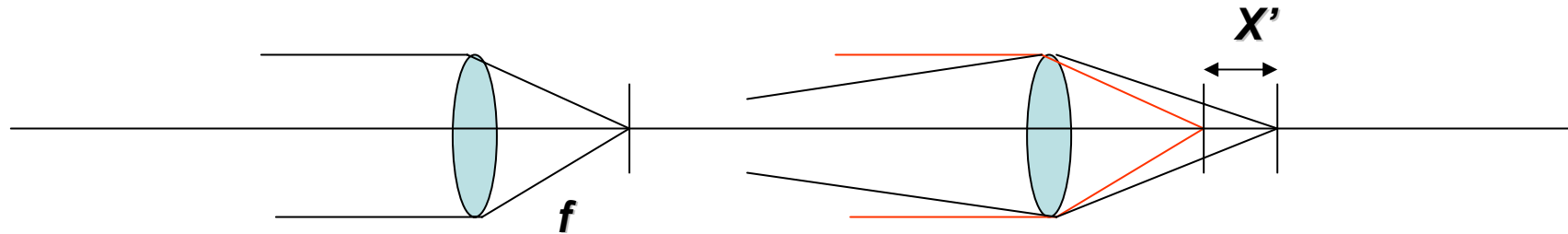


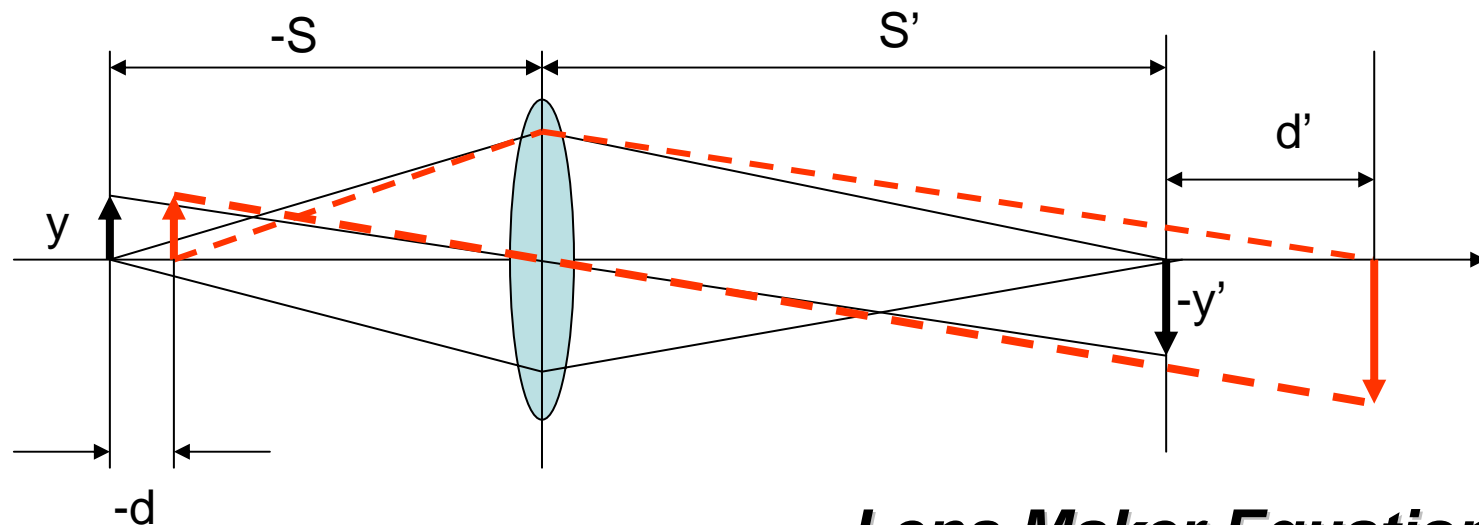
Illustration: focal plane backward shifting



Application: Macro lens (with mobile phone)										
		unit: mm								
effective focal length (mm)	f	10	9	8	7	6	5	4	3	2
closed distance (10 cm)		100	100	100	100	100	100	100	100	100
close to front focal point (mm)	(-x)	-90	-91	-92	-93	-94	-95	-96	-97	-98
	(-f)	-10	-9	-8	-7	-6	-5	-4	-3	-2
	f	10	9	8	7	6	5	4	3	2
focal plane back shifting (mm)	x'	1.111	0.890	0.696	0.527	0.383	0.263	0.167	0.093	0.041
	% with f	11.1%	9.9%	8.7%	7.5%	6.4%	5.3%	4.2%	3.1%	2.0%

Macro lens for mobile phone

Useful first-order relationship (2)



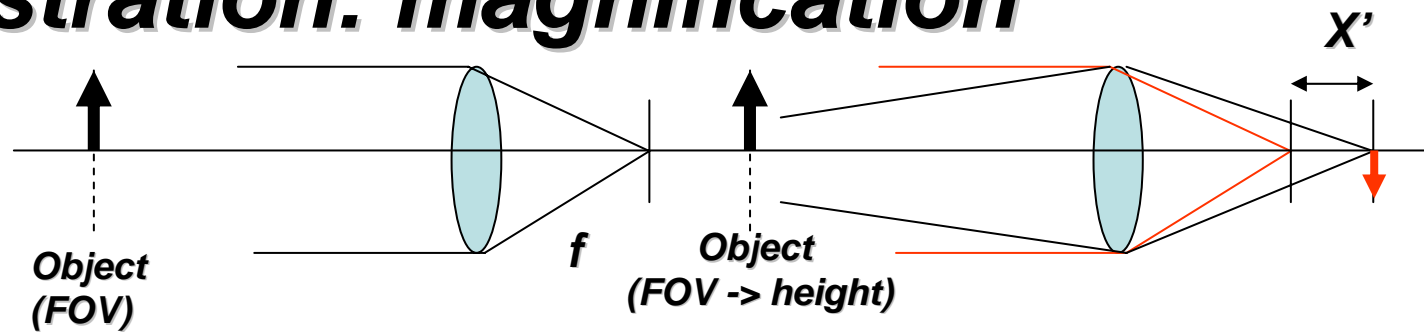
Lens Maker Equation

$$1/S' = 1/f + 1/S$$

Lateral magnification: $m = y'/y = s'/s$

Longitudinal magnification: $DS'/DS = d'/d = (y'/y)^2$

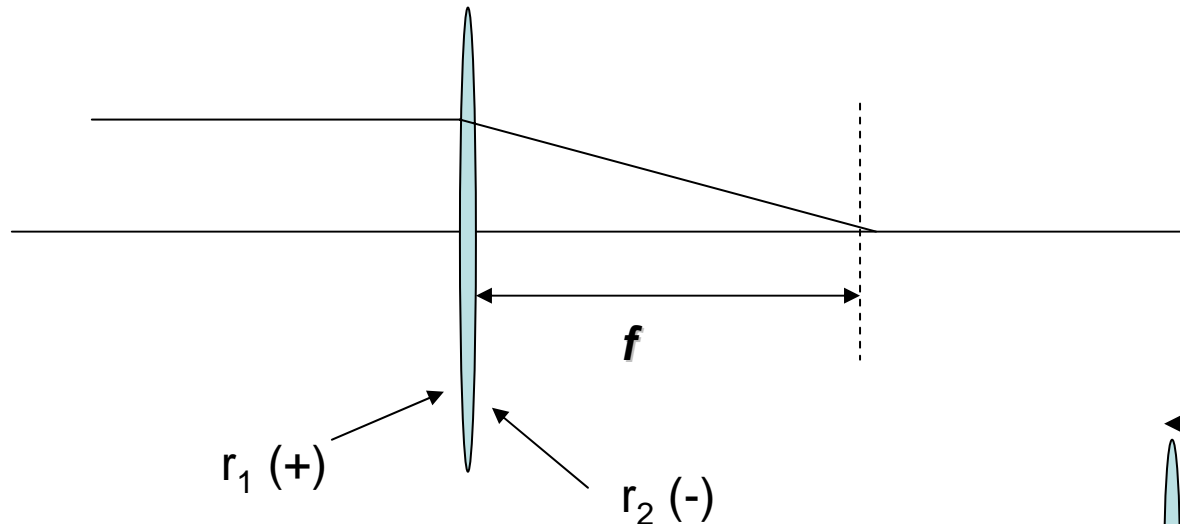
Illustration: magnification



Category	item	unit	mm							
Given	efl	10.00	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00
Given	object location (-s)	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
deduced	image location (s')	11.11	9.89	8.70	7.53	6.38	5.26	4.17	3.09	2.04
Given	object height (y)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
deduced	image height (-y')	-0.56	-0.49	-0.43	-0.38	-0.32	-0.26	-0.21	-0.15	-0.10
deduced	lateral magnification $m=y'/y=s'/s$	-0.111	-0.099	-0.087	-0.075	-0.064	-0.053	-0.042	-0.031	-0.020
	in % with y	-11.1%	-9.9%	-8.7%	-7.5%	-6.4%	-5.3%	-4.2%	-3.1%	-2.0%
deduced	longitudinal magnification $(d'/d=(y'/y)^2)$	0.012	0.010	0.008	0.006	0.004	0.003	0.002	0.001	0.000
	in% of object shifting	1.23%	0.98%	0.76%	0.57%	0.41%	0.28%	0.17%	0.10%	0.04%
	longitudinal magnification: image relocation with object shifting									

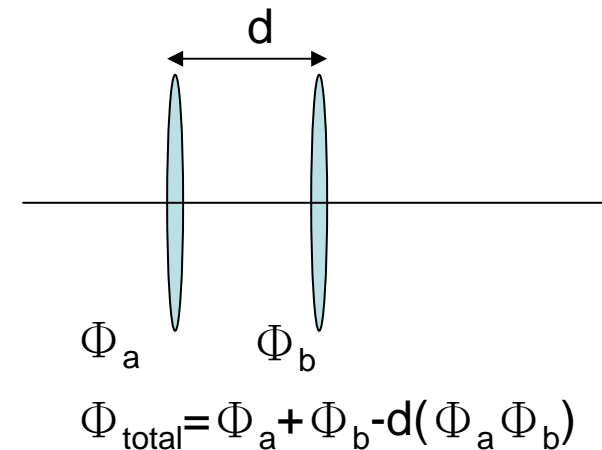
Useful first order relationship (3)

Optical power and focal length

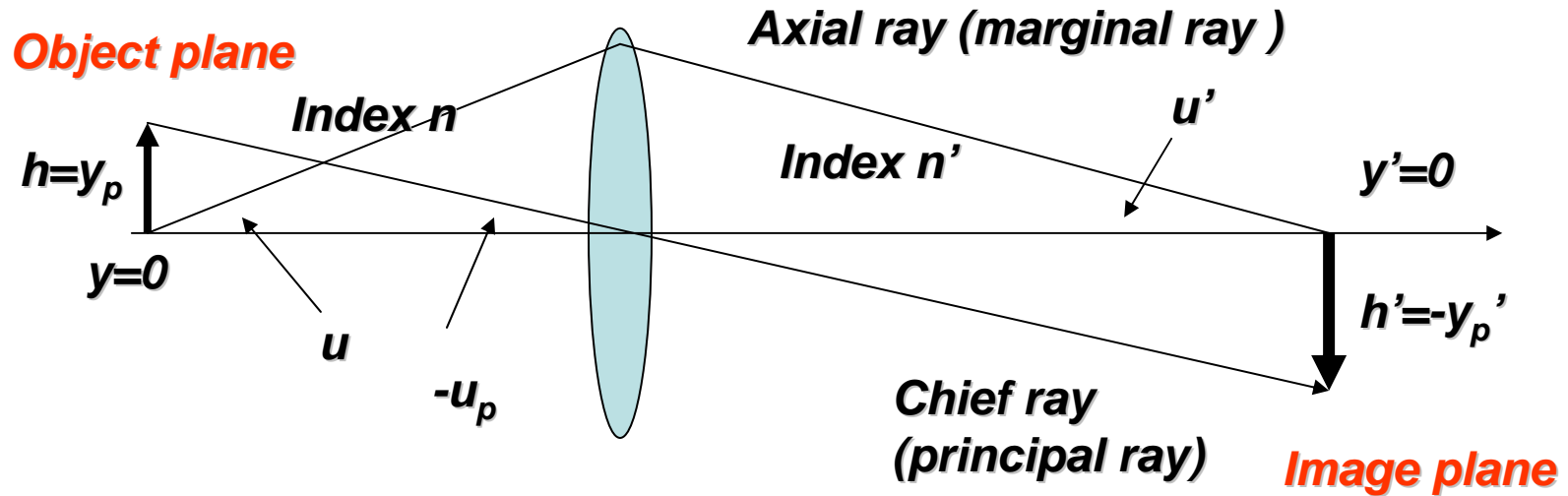


$$\text{Optical power } \Phi = 1/f = (n-1)(1/r_1 - 1/r_2)$$

Diopter /diopetre (屈光度)
(unit: 1/M; focal length is in a unit of meter)



Useful first order relationship (4)



Optical Invariant

(Lagrange invariant/ Helmholtz invariant)

$$I = y_p n u - y n u_p$$

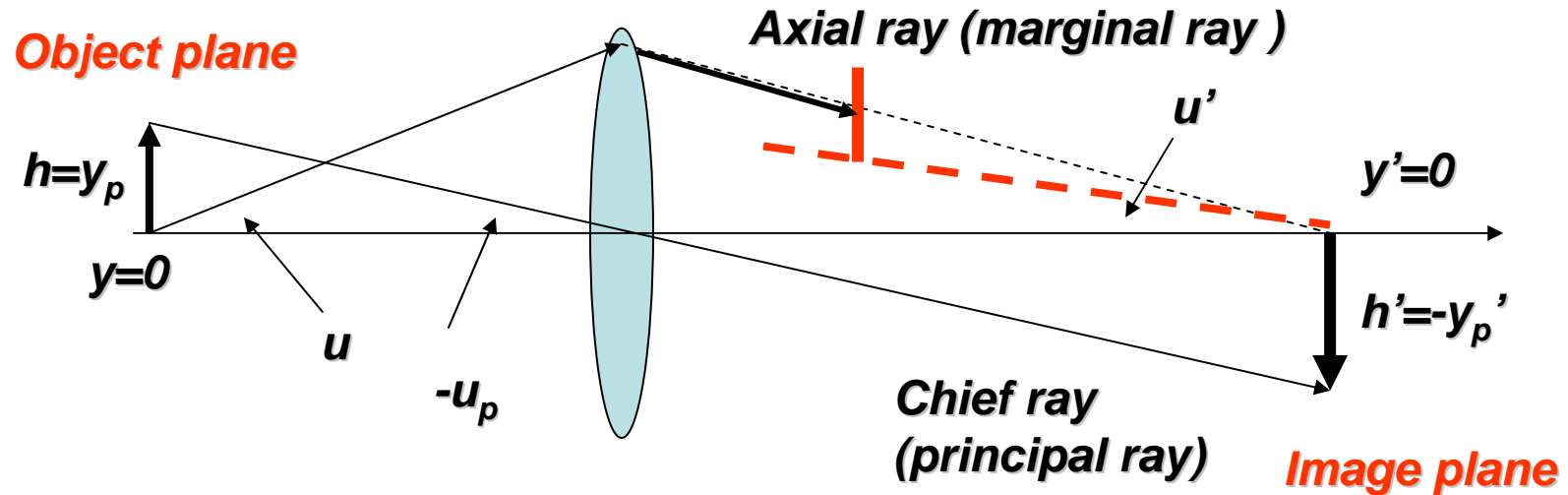
Object plane $I = h n u$

Image plane $I = h' n' u'$



$$I = h n u = h' n' u'$$

Illustration:



What happens if the invariant is violated?

$$I = hnu = h'n'u'$$

Ray is generally blocked, and hence more energy loss

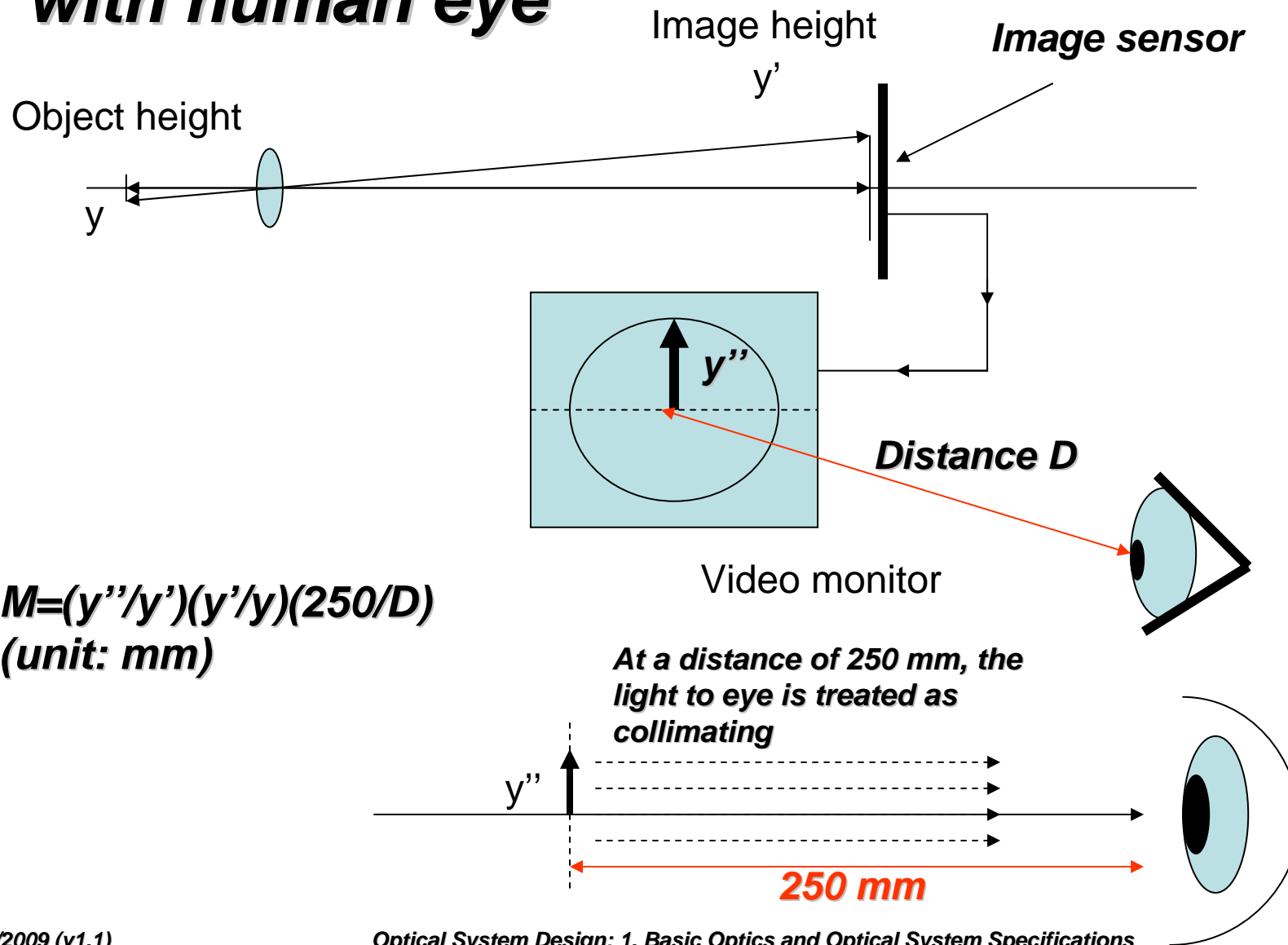
More in chapter 14

Useful first order relationship (5)

**With human eye, magnification is somehow different.
A scale of 250mm and observer distance is important!**

	Magnification	formula	Remarks
1	Microscope objective	$M_o = (y''/y)(250/D)$	Microscope with a video monitor Seeing by human eye $M = (y'/y)(y''/y') = (y''/y)$ times (250/D)
2	Magnifier (eye piece)	$M_e = \theta / \alpha = 250/f$	
3	Visual microscope	$M_m = M_o M_e$	M_o : the magnification of objective M_e : the magnification of eyepiece
4	Visual telescope	$M = f_o / f_e = D/d = \theta / \alpha$	

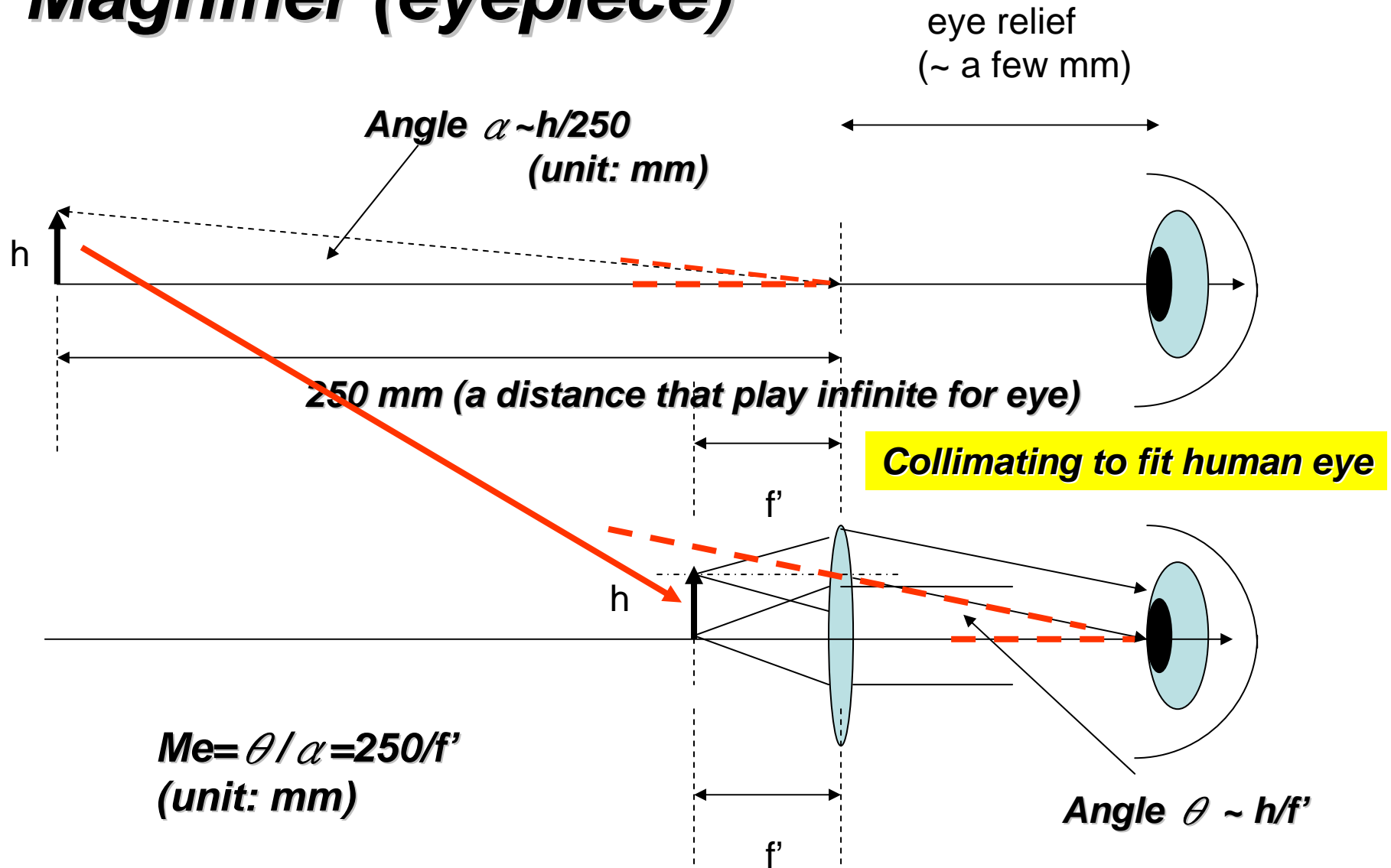
Microscope with video monitor with human eye



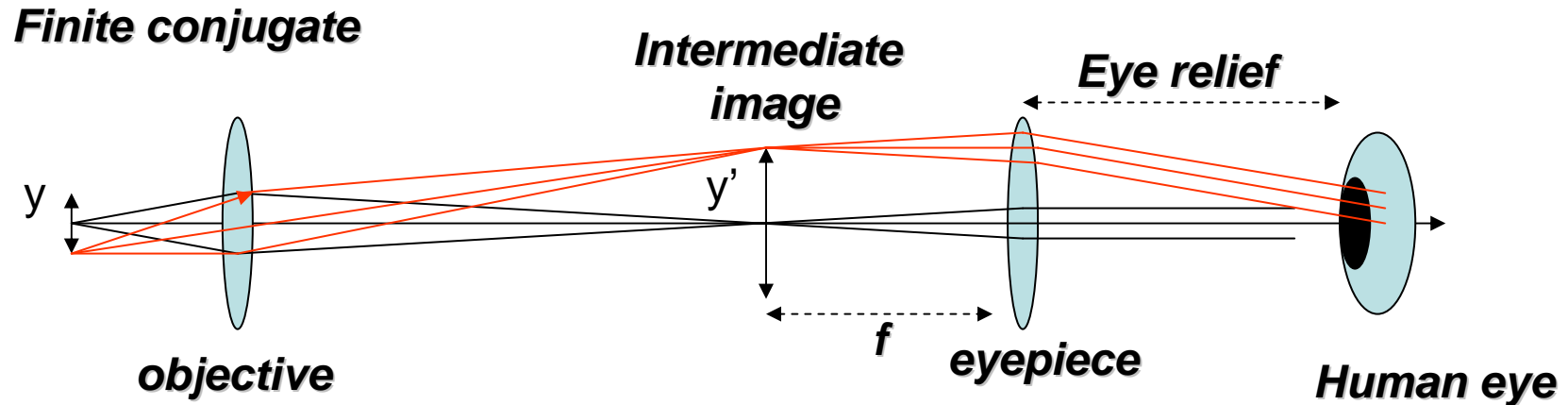
$$M = (y''/y')(y'/y)(250/D)$$

(unit: mm)

Magnifier (eyepiece)



Magnification of a visual microscope



$$M_e = 250 / f \text{ (unit: mm)}$$

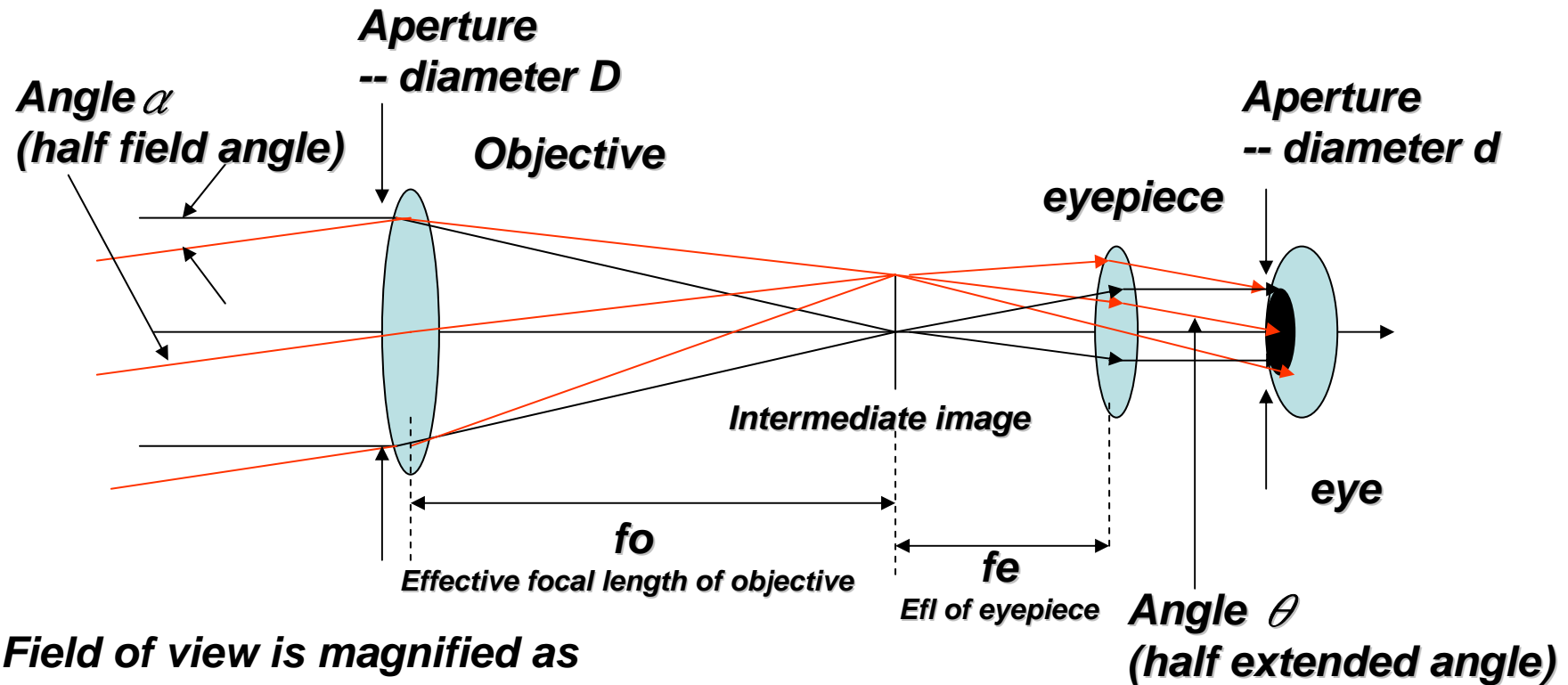
$$M_o = \text{magnification of objective} = y' / y$$

The magnification of the whole system

$$M = M_o * M_e$$

Magnification of a visual telescope

Afocal system



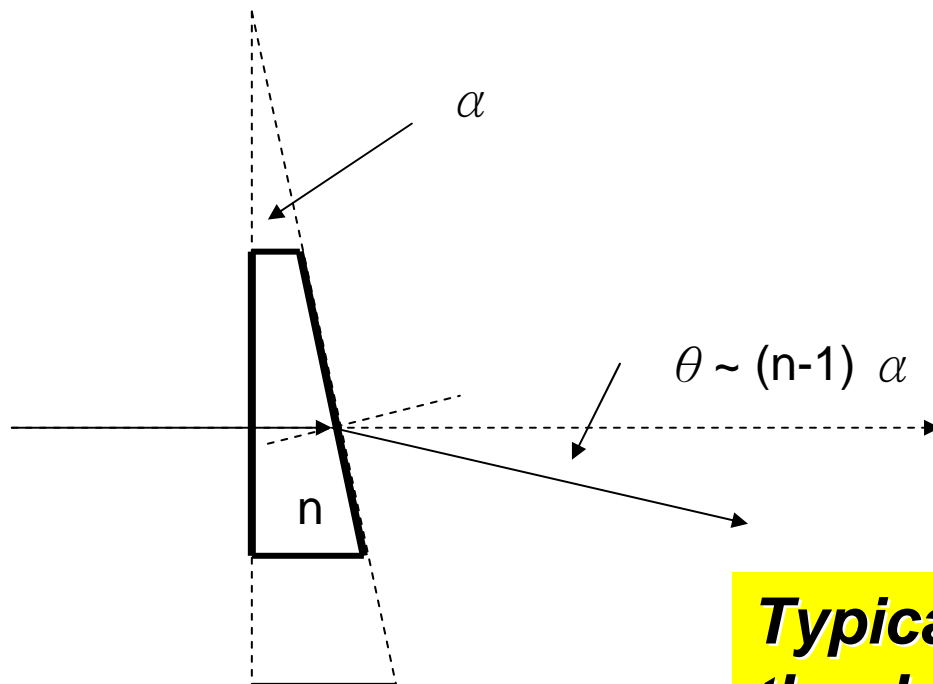
Field of view is magnified as

$$M = \theta / \alpha = f_o / f_e = D / d$$

D ~ entrance pupil of the system; d : exit pupil of the system
(d is the entrance pupil of eye, too.)

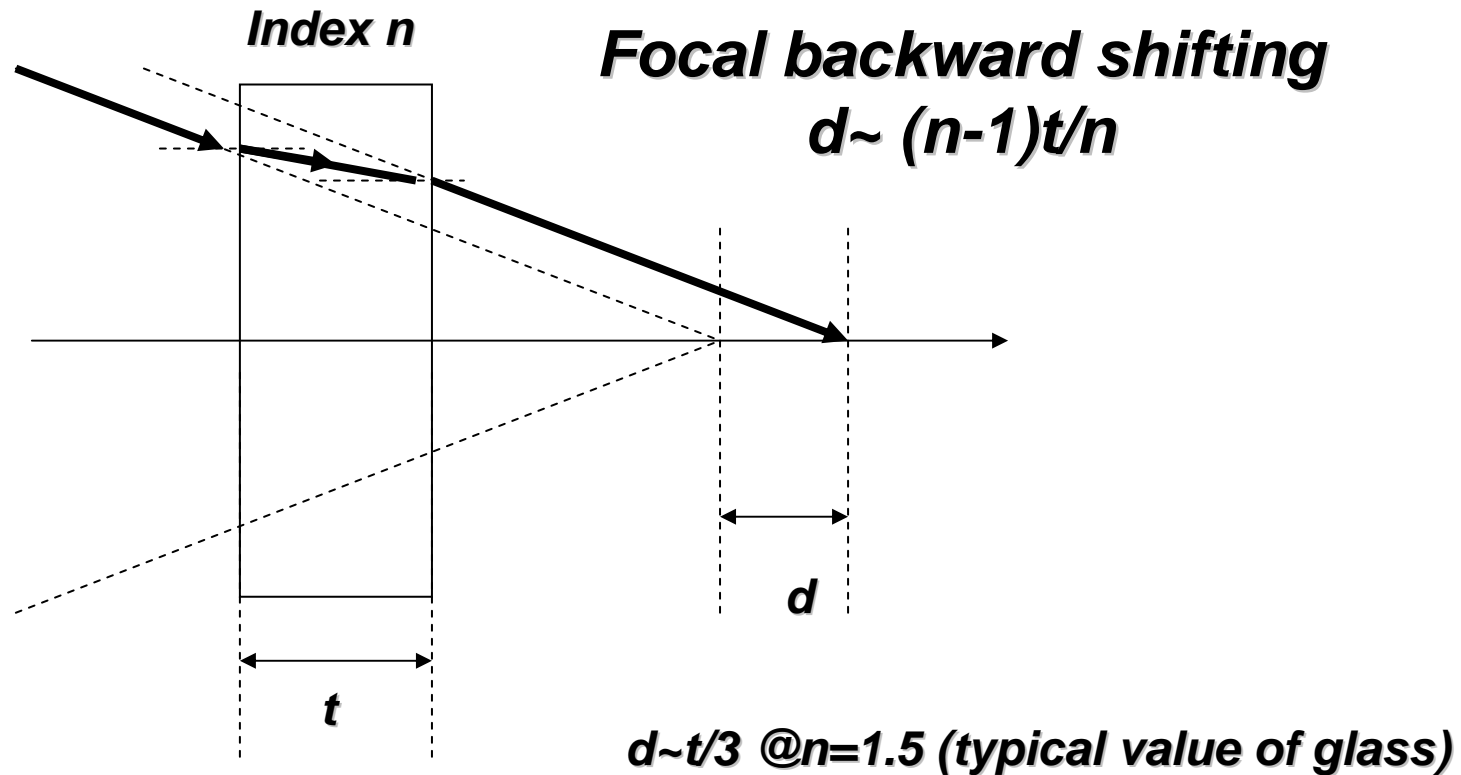
Useful first-order relationship (6)

Light deviation through wedge plate



**Typically for a glass of $n=1.5$,
the deviation angle $\theta \sim 0.5 \alpha$**

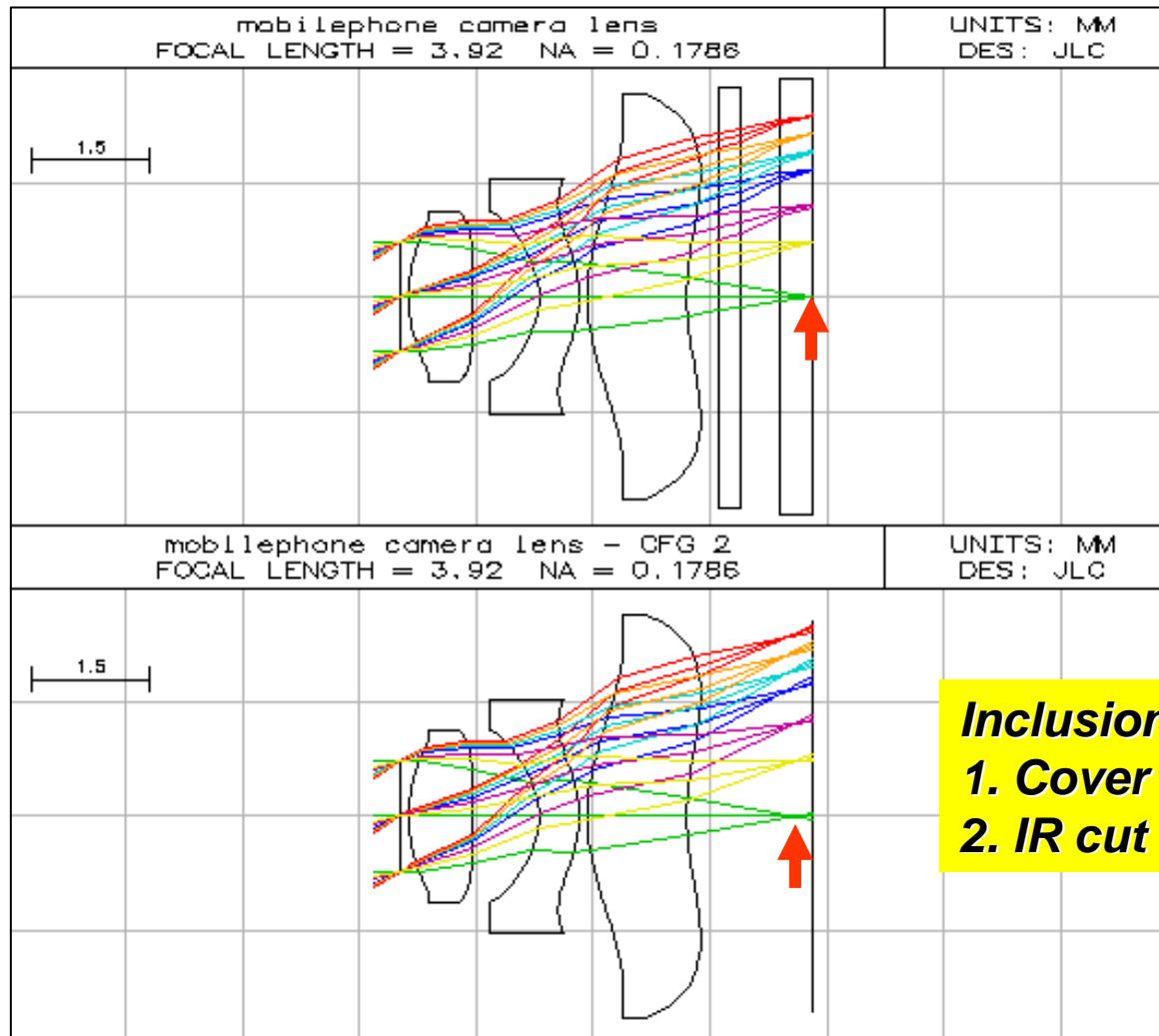
Useful first order relationship (7)



Typically with a glass of 0.3 mm the focal plane will be shifted ~ 0.1 mm.

d and t in a unit of mm

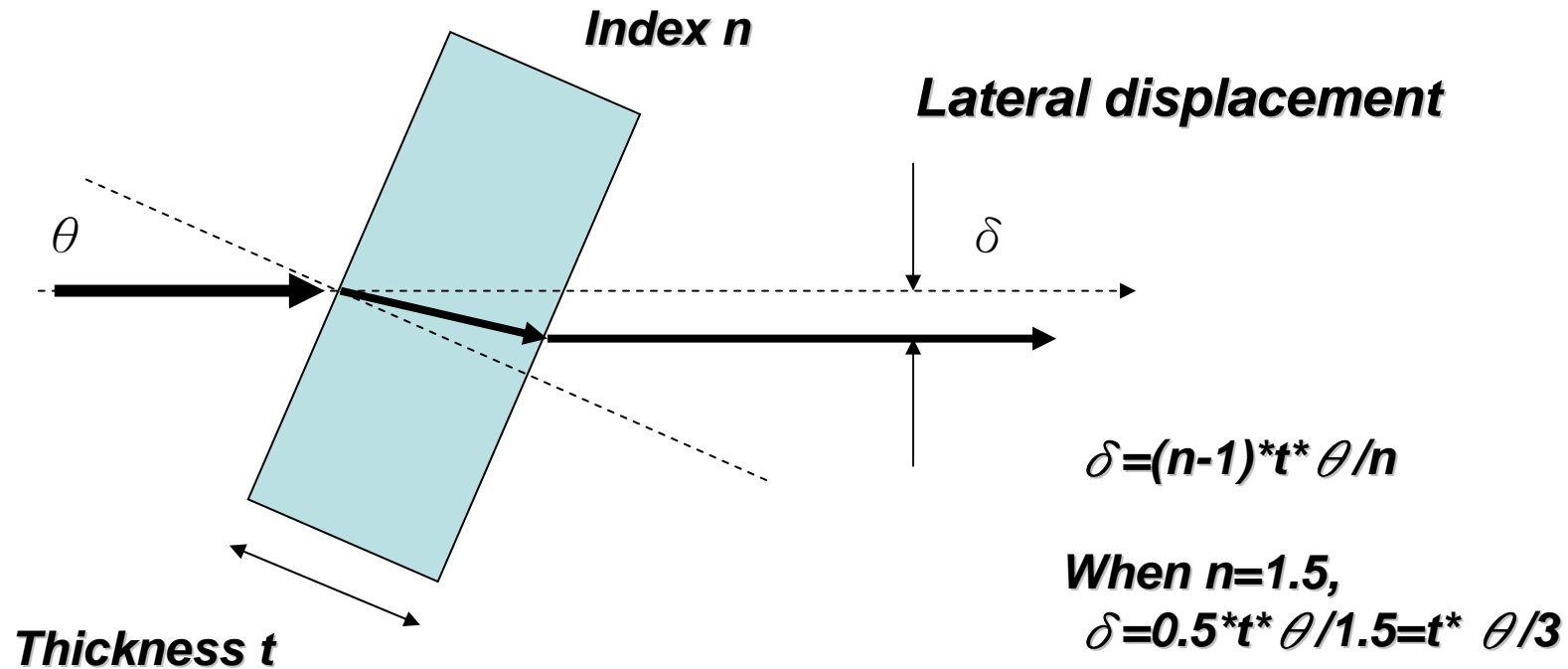
Numerical illustration



Inclusion and no inclusion of

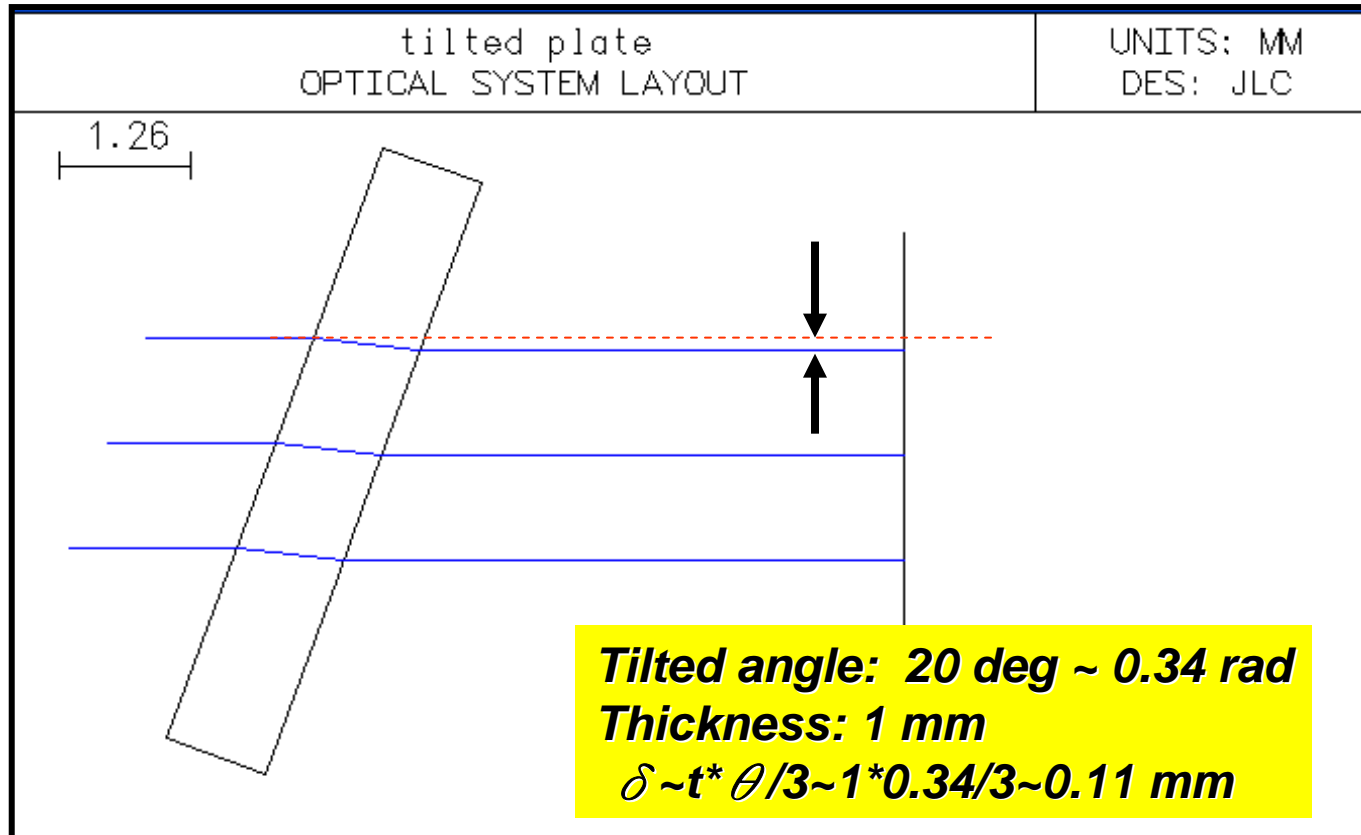
- 1. Cover glass ~ 0.4 mm**
- 2. IR cut filter ~ 0.3 mm**

Useful first order relationship (8)



Unit: θ : in rad δ in mm

Numerical illustration



Homework 1: X5 magnifier

- Design an X5 magnifier with simple bi-convex singlet
 - List your specification
 - Drawing your system layout
 - Do your paraxial optics analysis

Homework 2: Progressive addition lens

- Consider a progressive addition lens (PAL)
 - List the specification
 - Drawing your system layout
 - Do your paraxial optics analysis

It is interesting to note that the first patent of PAL can be traced back to 1908

• *O. Aves, Improvements in and relating to Multifocal lenses and the like, and the method of Grinding Same.*

GB Patent 15,735 (1908)

More information could be found in

http://en.wikipedia.org/wiki/Progressive_lenses