Reading Aberrations

Lens Design OPTI 517

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Reading aberrations

- We cannot intelligently improve a lens system if we cannot recognize its aberrations
- Wave aberration fans
- It is critical that we learn to ‘read’ the aberrations of an optical system

Field of view

- Very small FOV: arc seconds, minutes
- Small FOV: sub-degree to a few degrees
- Small FOV: 5 to 30 degrees
- Medium FOV: 30 to 60 degrees
- Wide angle: > 60 degrees
- Hyper FOV: >180 degrees

Field of view

- Eye resolution and field of view
- The Moon
- The Sun
- 35 mm camera (f=50 mm)

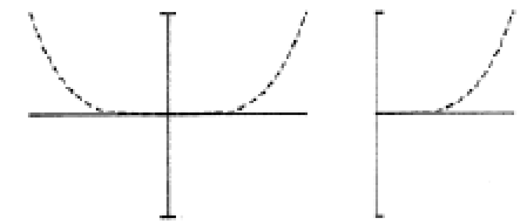
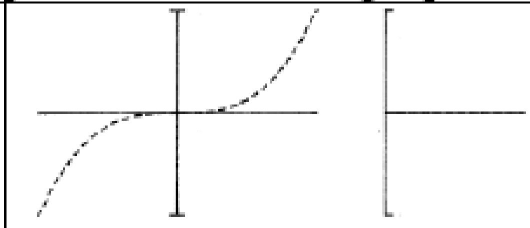
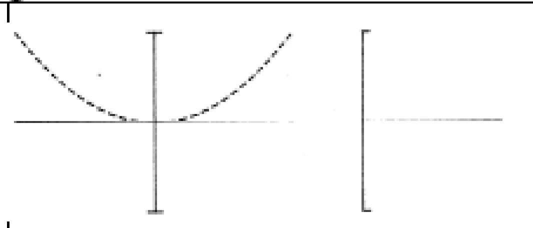
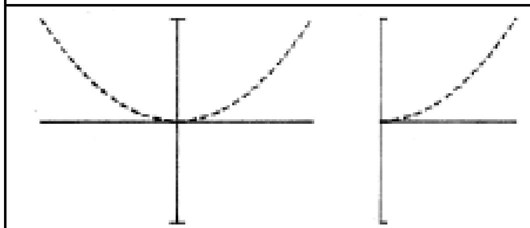
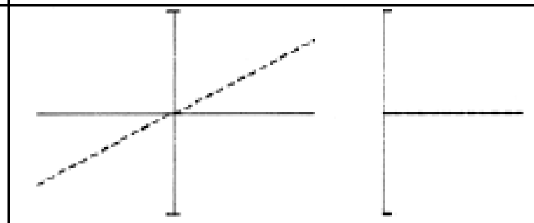
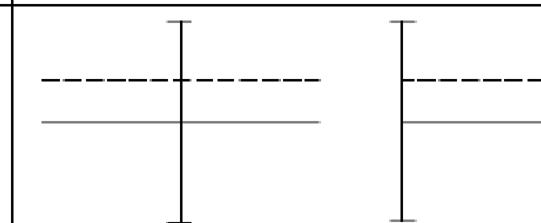
Speed

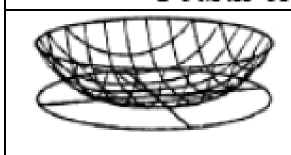
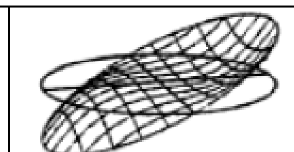
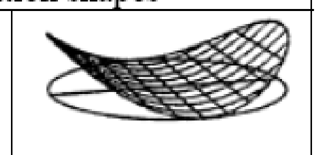
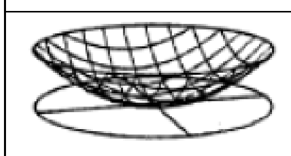
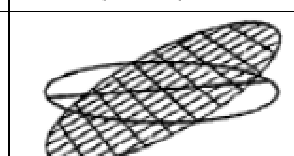
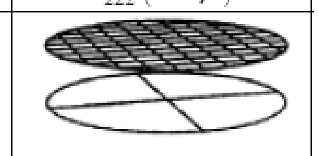
- F/# > 10 slow
- F/# < 2.8 fast

- Eye speed?

Display of aberrations

- Historical nature
- Transverse ray aberration fans
- <u>Wave aberration fans</u>
- <u>Field curves</u>
- Aberration coefficients
- Spot diagrams
- Zernike decomposition
- Total aberration vs fourth-order

Fourth-order wave aberrations fans Left plot: meridional. Right plot sagittal.		
		
$W_{040}(\vec{\rho}\cdot\vec{\rho})^2$	$W_{131}(\vec{H}\cdot\vec{\rho})(\vec{\rho}\cdot\vec{\rho})$	$W_{222}(\vec{H}\cdot\vec{\rho})^2$
		
$W_{220}(\vec{H}\cdot\vec{H})(\vec{\rho}\cdot\vec{\rho})$	$W_{311}(\vec{H}\cdot\vec{H})(\vec{H}\cdot\vec{\rho})$	$W_{400}(\vec{H}\cdot\vec{H})^2$

Fourth-order wavefront aberration shapes		
		
$W_{040}(\vec{\rho}\cdot\vec{\rho})^2$	$W_{131}(\vec{H}\cdot\vec{\rho})(\vec{\rho}\cdot\vec{\rho})$	$W_{222}(\vec{H}\cdot\vec{\rho})^2$
		
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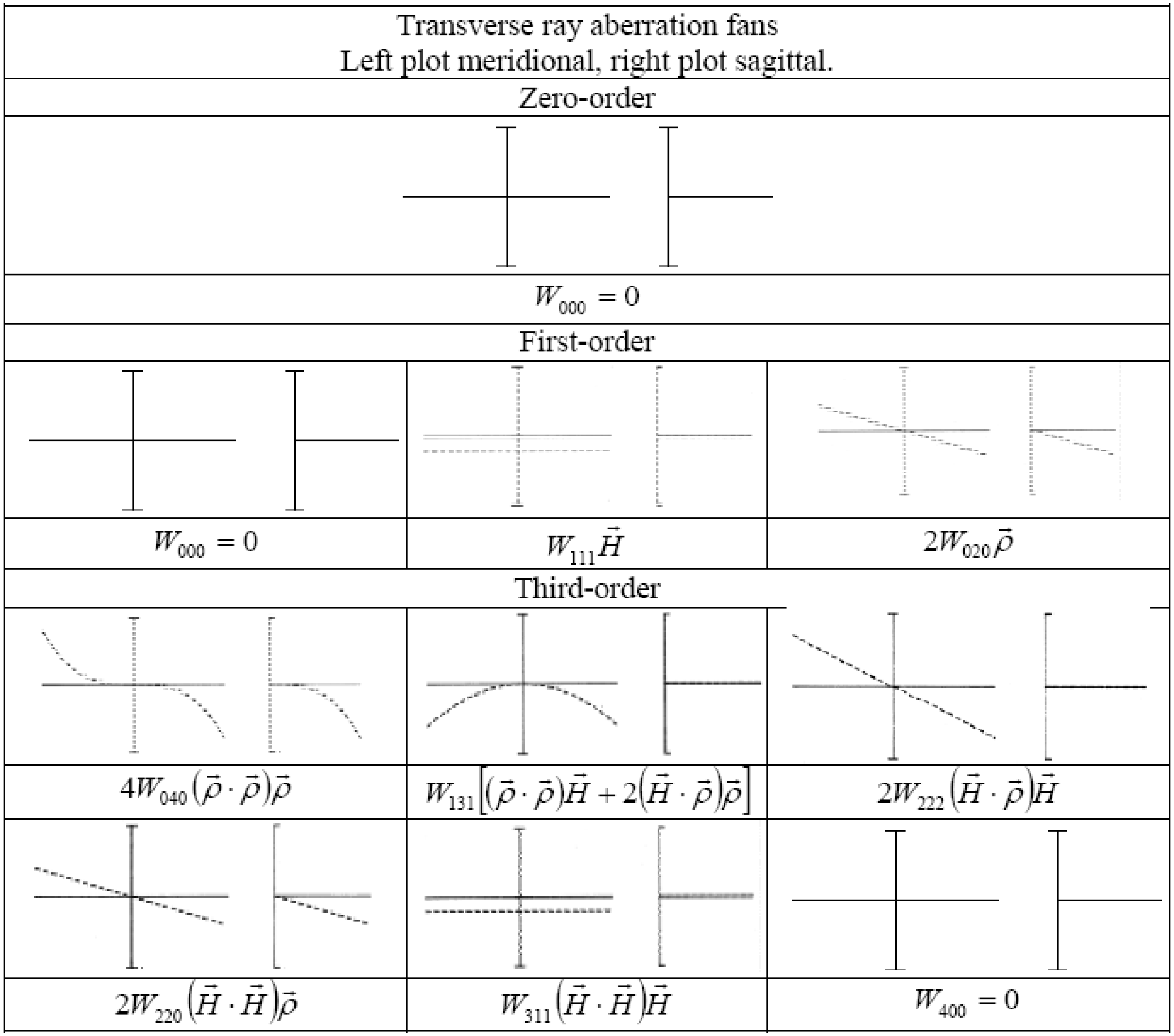


$$\vec{\varepsilon} = \bar{y}_I \Delta\vec{H}$$

$$\Delta\vec{H} = -\frac{1}{Ж}\vec{\nabla}_{\rho} W$$

Guide to identifying aberrations from wave-fans

Monochromatic

1) Be aware of the speed and field of view
2) First, pay attention to the on axis aberrations

•is it properly in focus ?
•is there spherical aberration W040?
•is there higher order spherical?
•what are the magnitudes?

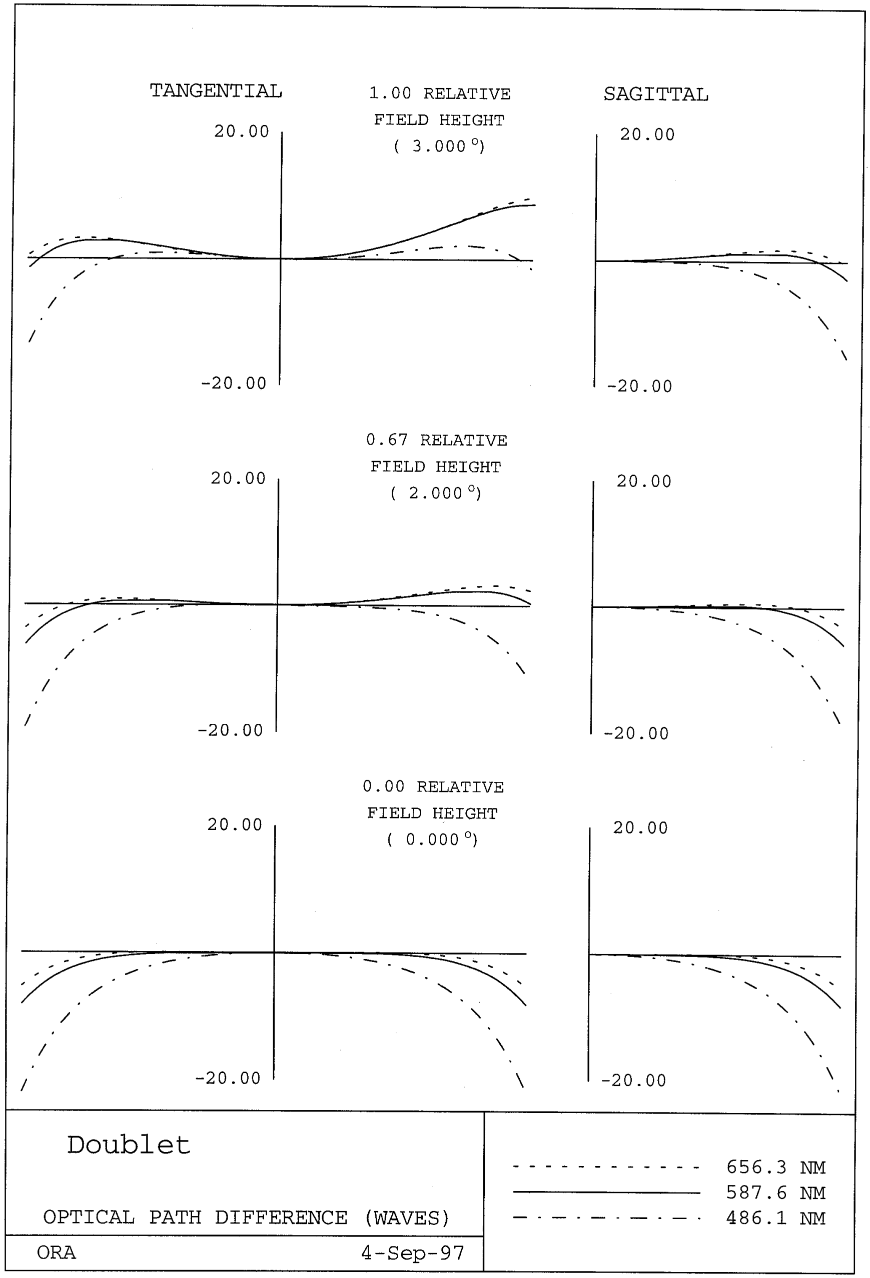
3) Second, take a look at the full field aberrations

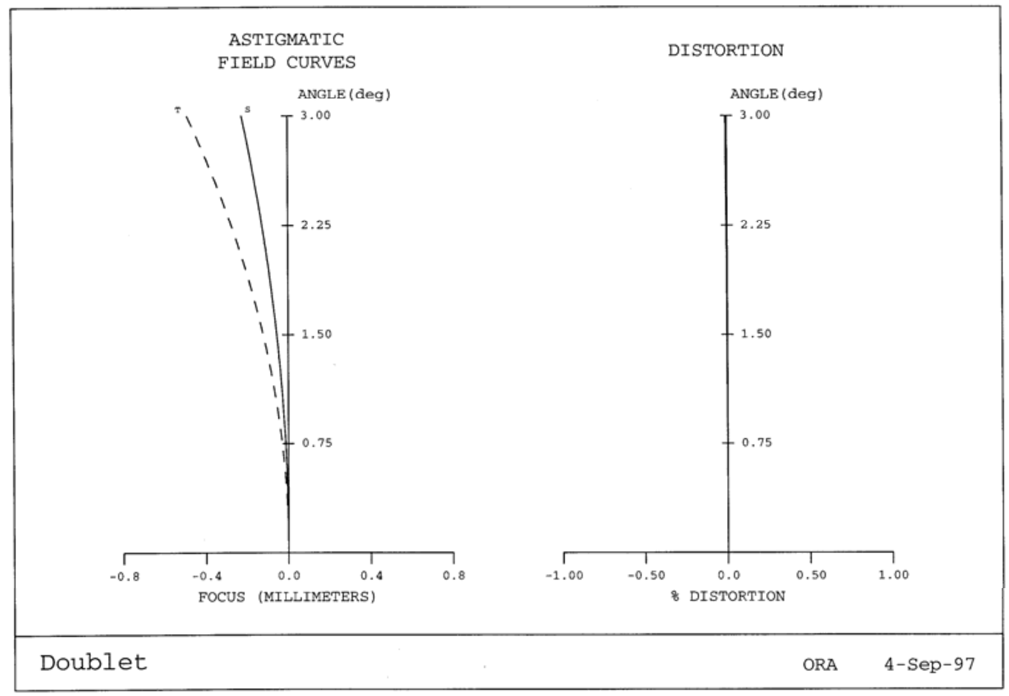
•spherical
•astigmatism
•coma
•Field curvature
•higher order

Guide to identifying aberrations from wave-fans

4) Take a look at the 7/10 field
5) Verify with field curves, spot diagrams, and fourth-order coefficients

- Note: Real ray wavefront fans have fourth-order aberrations as components.
- Slow systems with small fields may be well described by fourth-order theory.





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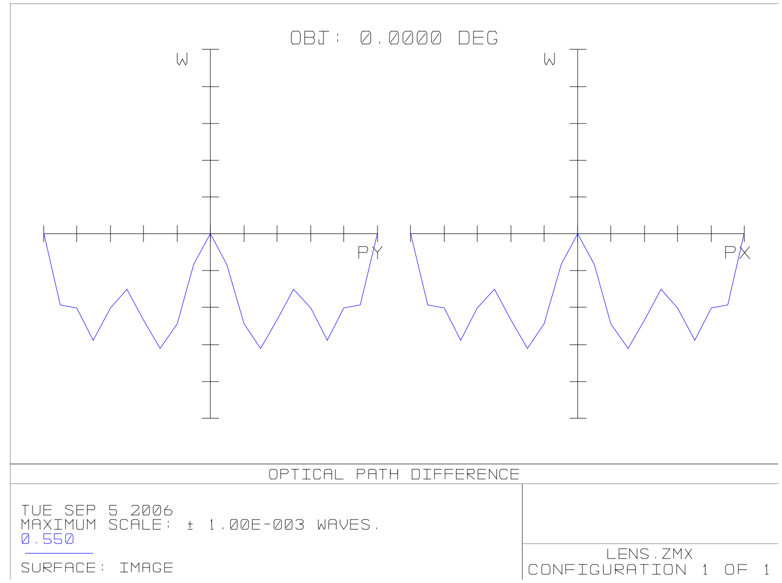
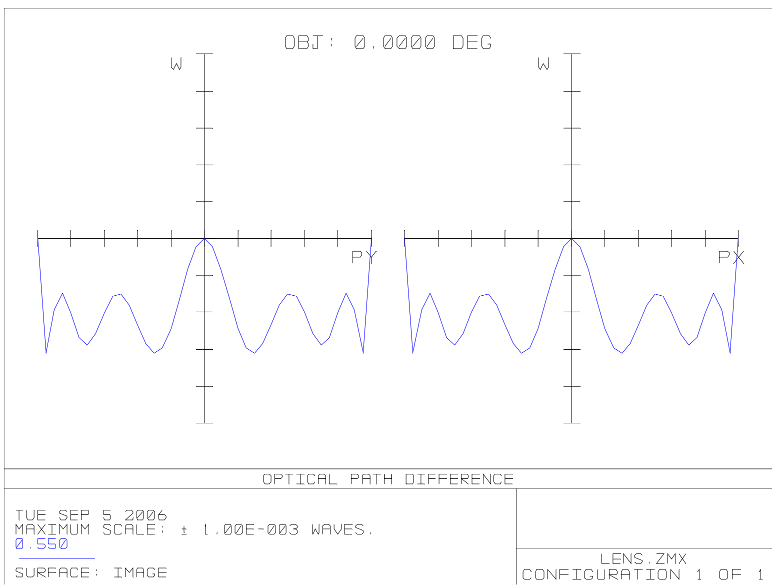
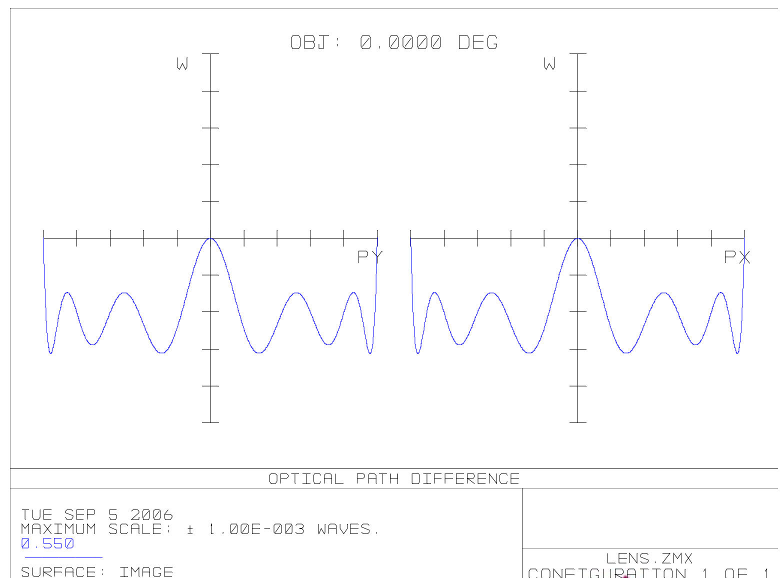
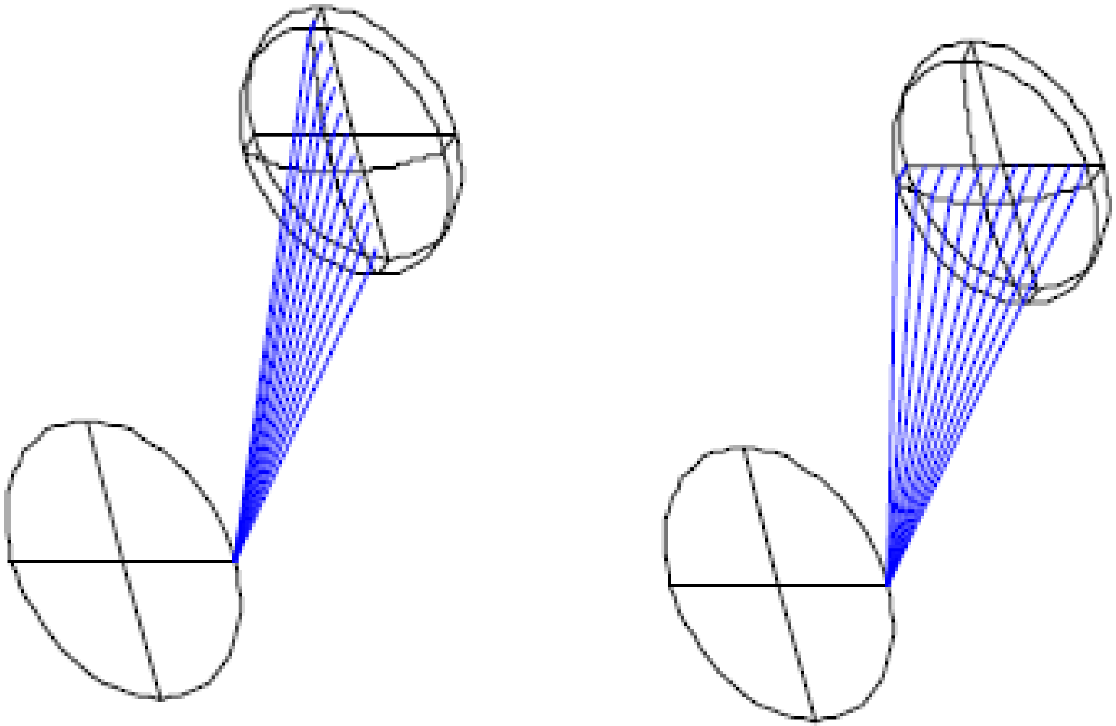
What is going on here?







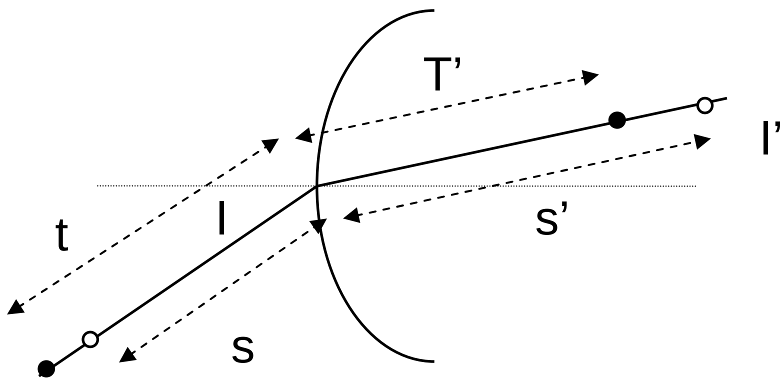
Meridional and Sagittal planes



•A meridional plane contains the optical axis
•Sagittal from the Latin meaning arrow

Coddington Equations

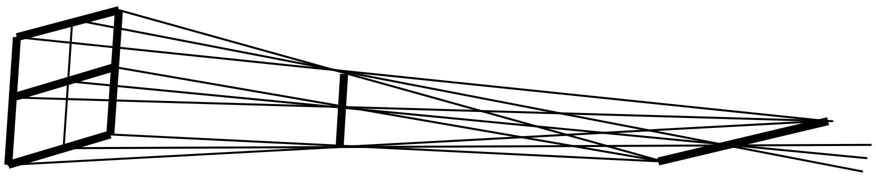
$$\frac{n'}{s'} - \frac{n}{s} = \frac{n'\cos I' - n\cos I}{R_s} \qquad \frac{n'\cos^2 I'}{t'} - \frac{n\cos^2 I}{t} = \frac{n'\cos I' - n\cos I}{R_t}$$

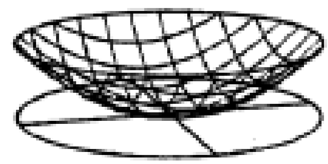


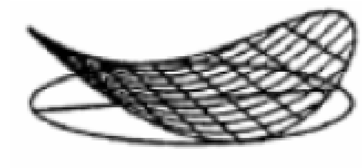
s is the distance along the ray from the object point to the surface vertex
s' is the distance along the ray from the surface vertex to the image point
t is the distance along the ray from the object point to the surface vertex
t' is the distance along the ray from the surface vertex to the image point
Rs is the saggital radius of curvature at the intersection point
Rt is the tangential radius of curvature at the intersection point

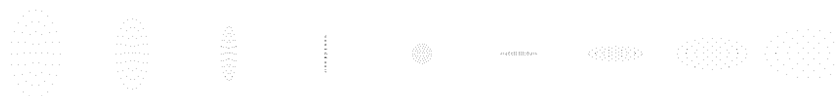
- Actually Thomas Young equations
- Note change of aberration metric: longitudinal

Astigmatism

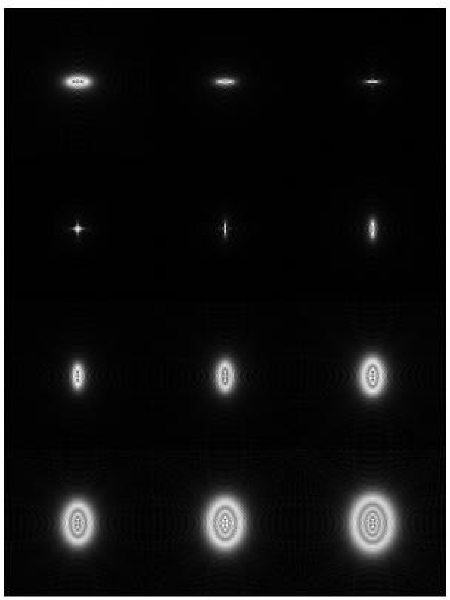


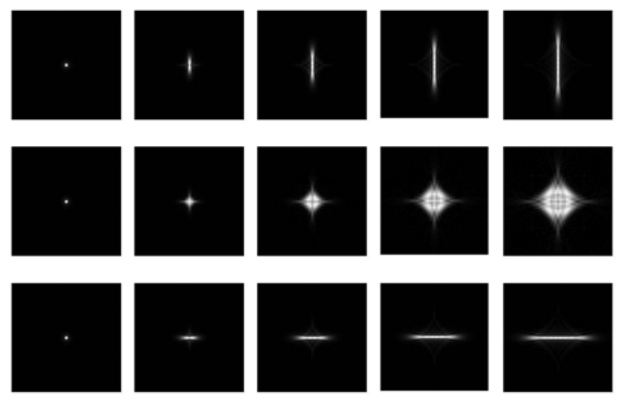






Minimum defocus Ad=-2 Defocus unit step =0.5





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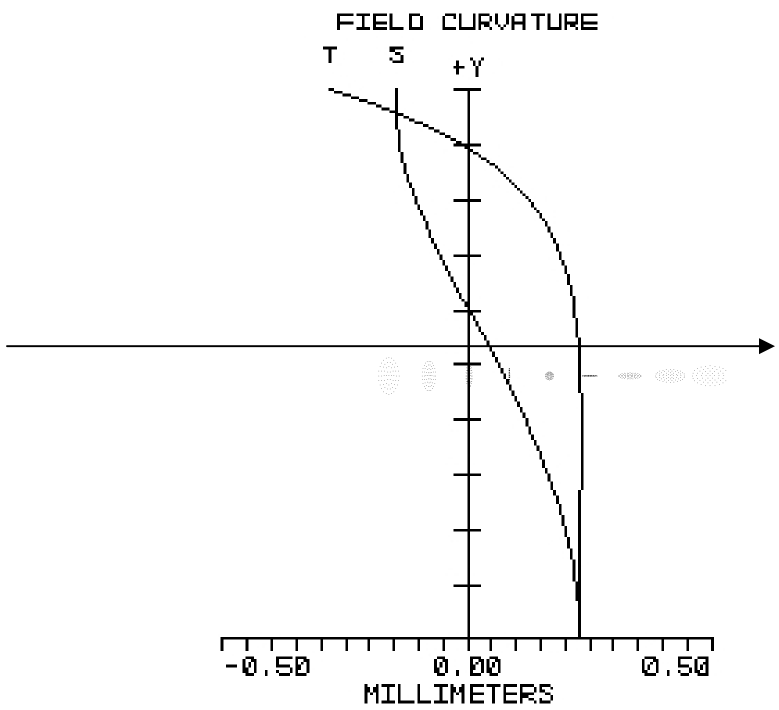
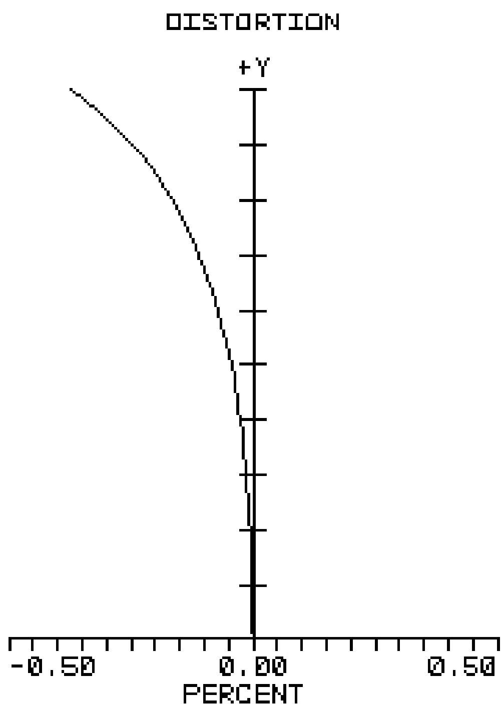
Field curves





Distortion=(H-h)*100/h

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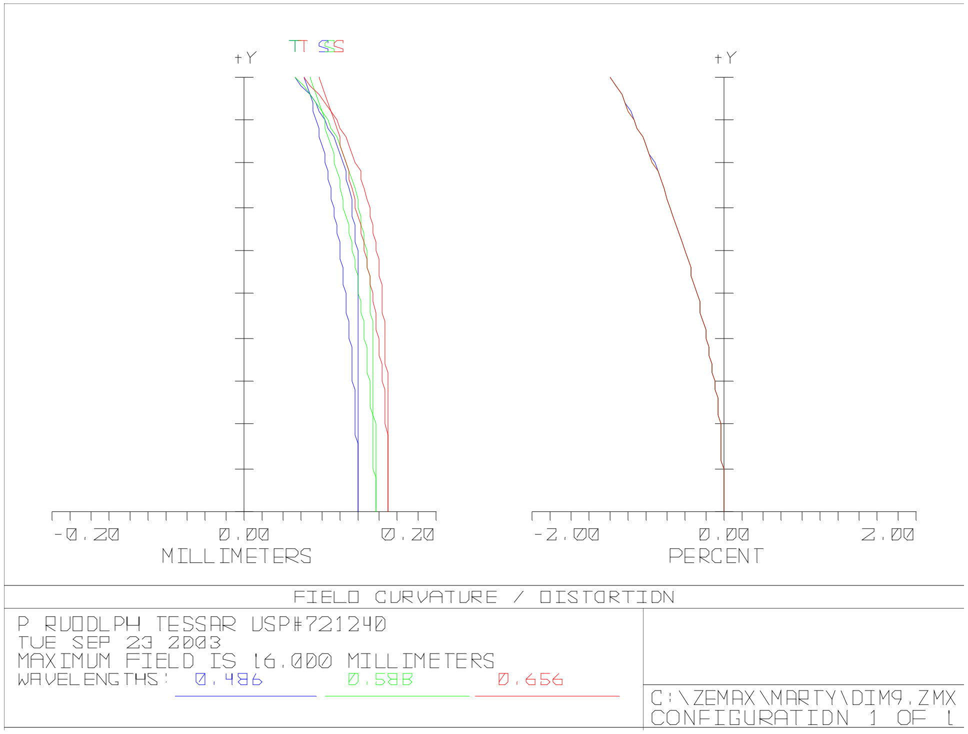

Program may trace two close real rays

Distortion=(H-h)*100/h

Summary

- Being aware of the system speed and FOV
- Knowing how to read/identify aberrations
- Coddington/Thomas Young equations
- Article by R. Kingslake

  WHO DISCOVERED CODDINGTON'S Equations?

  Optics and Photonics News, Vol. 5, Issue 8, pp. 20-23 (1994)