Lenses

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Lenses

• In a photo system, the lens is most critical
• Lenses are characterized by
  – Prime vs. zoom
  – Focal length (field of view)
  – Maximum aperture (the f number like f/2.8)
  – Various gizmos (e.g. image stabilization, faster autofocus)
  – More complex quality issues
  – Minimum focusing distance
• Max aperture is usually correlated with quality
• Warning: lenses are addictive
Why are lenses so complex?

- It’s not so easy to send light where it should go

Figure-11
Cross-Section of the EF24-70mm f/2.8L USM

source: canon red book
Lens quality varies!

source: the luminous landscape
Center is usually OK

- [http://www.photo.net/equipment/canon/70-300do_2/](http://www.photo.net/equipment/canon/70-300do_2/)

*250x500 pixel crops, centre of frame f5.6*
Image corners are often sacrificed

- [http://www.photo.net/equipment/canon/70-300do_2/](http://www.photo.net/equipment/canon/70-300do_2/)

- 70-300 f5.6 corner
- 75-300 f5.6 corner
- 100-400 f5.6 corner

250x500 pixel crops, corner of frame f5.6
Max aperture is tough

- http://www.photo.net/equipment/canon/70-300do_2/

250x500 pixel crops, centre of frame f5.6
Gets better when stopped down

- http://www.photo.net/equipment/canon/70-300do_2/

250x500 pixel crops, centre of frame f11
Copy variation

- Left: Addy's 100-400; Right: Frédo's
- (full aperture, 135mm)
Aberrations

- Geometrical optics: hard to focus all rays
- Wave optics: diffraction problems

Figure 3.1
Image Quality, Geometrical Aberrations (Top) and Diffraction Limited (Bottom)

From Optical System Design by Fisher and Tadic
The idiocy of Megapixels

Third-order aberrations
Spherical aberration

• Rays don’t focus at same position

source: Hecht Optics
Chromatic aberration

- The previous aberrations depend on wavelength (because of varying index of refraction)

Figure 18: Chromatic Aberration

This phenomenon occurs because the prism's index of refraction varies depending on the wavelength (color).

Transverse chromatic aberration (lateral chromatic aberration)

Parallel light rays

Optical axis

Off-axis object point

Axial chromatic aberration (longitudinal chromatic aberration)

Photo-3 Axial chromatic aberration

Photo-4 Transverse chromatic aberration

Source: Canon Red Book
Comatic aberration

Figure-20 Comatic Aberration

This is the phenomenon where the diagonal light rays do not focus on one point on the image surface.

This is the phenomenon where there is a tail like that of a comet.

- Inward coma
- Outward coma

Off-axis parallel pencil of rays

Optical axis

source: canon red book
Comatic aberration

From Hecht's Optics
Astigmatism

Figure-21 Astigmatism

- This is the phenomenon where there is no point image

source: canon red book
Defects

Photo-2  The photographs are magnifications of the subject and surrounding area from part of a test chart photographed with a 24mm x 36mm film frame and printed on quarter size paper.

Almost ideal image formation

Peripheral  □  part magnified

① Example of spherical aberration

②-1 Example of inward coma

③ Example of astigmatism

②-2 Example of outward coma

source: canon red book
Curvature of field

Figure-22  Curvature of field

This is the phenomenon where a good image focus surface is bent.

○ This is an ideal lens with no image bending.

Subject surface  Focus surface

Subject  ○ Occurrence of image bending

source: canon red book
Curvilinear distortion

(a) Barrel distortion and Pincushion distortion

(b) Object grids and Images grids for Barrel distortion and Pincushion distortion.

Figure 6.10 The effects of curvilinear distortion. (a) The selection of a geometrically incorrect ray bundle by asymmetric location of the aperture stop. (b) Image shape changes caused by barrel and pincushion distortion.

From "The Manual of Photography" Jacobson et al
Achromatic doublet

Figure 6.38  An achromatic doublet. The paths of the rays are much exaggerated.

From Hecht's Optics
Radial distortion

source digital outback
Software

- http://www.tawbaware.com/maxlyons/pano12ml.htm

From DXO

Distortion affects different parts of the color spectrum differently (prism effect) and creates the so called "lateral chromatic aberration", which results in color fringes around high/low-light transitions. With the ever increasing sensor resolutions, lateral chromatic aberration becomes more and more visible, in turn making it more and more important to precisely address distortion for each color plane.

Longitudinal chromatic aberration, purple fringing, coma, and so on can also cause color fringes, which are automatically removed by DxO Optics Engine v2.

From DXO
Other quality issues
**Flare**

Figure 5.6  Formation of flare spots by a simple lens. Images of the source are formed at distances $A$ and $B$, where:

$$A = \left( \frac{n - 1}{an - 1} \right) f$$

$$B = \left( \frac{n - 1}{bn - 1} \right) f$$

and $a = 2, 4, 6 \ldots$, $b = 3, 5, 7 \ldots$ For $n = 1.5$, $A = f/4, f/10, f/16$ etc. and $B = f/7, f/13, f/19$ etc.

From "The Manual of Photography" Jacobson et al
Example of flare "bug"

• Some of the first copies of the Canon 24-105 L had big flare problems

• [Link to review](http://www.the-digital-picture.com/Reviews/Canon-EF-24-105mm-f-4-L-IS-USM-Lens-Review.aspx)
Use a hood! (and a good one)

Adapted from Ray's Applied Photographic Optics
Coating

- Use destructive interferences
- Optimized for one wavelength

Figure 5.7 An anti-reflection coating on glass using the principle of destructive interference of light between reflections $R_1$ and $R_2$

Figure 5.8 The effects on surface reflection of various types of anti-reflection coatings as compared with uncoated glass (for a single lens surface at normal incidence)

From "The Manual of Photography" Jacobson et al
Lens hood

Plate 15.1  Lens flare with an uncoated lens
(a) Flare effects. (b) Reduction of flare by use of a lens-hood.

From Ray's Applied Photographic Optics
Vignetting

- http://www.photozone.de/3Technology/lenstec3.htm
Vignetting

- The periphery does not get as much light
Quality evaluation
LPIs

- Line pair per inch

Input

After lens

http://www.imatest.com/docs/sharpness.html

Sharpness

\[ f_{50} = 1e+004 \text{ lp/mm}; \text{flens} = 61 \text{ lp/mm}; \text{lord} = 2 \]

- Sine pattern: Original
- Sine pattern: Lens only
- Bar pattern: Original
- Bar pattern: Lens only

Amplitude

MTF %

Line pairs per mm; MTF = 50%, 10% @ 61, 183/mm
MTF

- Modulation Transfer Function
- Pretty much Fourier transform of lens response
- Complex because needs to be measured at multiple locations

Table 3

<table>
<thead>
<tr>
<th>Spatial frequency</th>
<th>Maximum aperture</th>
<th>F8</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 lines/mm</td>
<td>S</td>
<td>M</td>
</tr>
<tr>
<td>30 lines/mm</td>
<td>S</td>
<td>M</td>
</tr>
</tbody>
</table>

Graph 5: MTF Characteristics

Here the x axis is image location

Source: Canon Red Book
Blur index based on Photoshop!

- Lens sharpness (or lack thereof) expressed as the amount of Photoshop blur that would blur the image similarly

- 50mm f/1.4: [http://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/2](http://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/2)
Lens design
Optimization software

• Has revolutionized lens design
• E.g. zooms are good now

From Hecht's Optics
Lens design, ray tracing

source: canon red book
Optimization

- Free parameters
  - Lens curvature, width, position, type of glass
  - Some can be fixed, other vary with focal length, focus (e.g. floating elements)
  - Multiplied by number of lens elements
- Energy/merit function
  - MTF, etc.
  - Black art of massaging the merit function
- Optimize for
  - All image locations
  - All wavelengths
  - All apertures
  - All focusing distances
  - All focal lengths (zoom only)
- Usually uses simulated annealing
Image stabilization
Image stabilization

1. Lens when still
   - To subject
   - Focal plane
   - IS lens group

2. Camera shaken
   - Camera shake

3. Camera shaking corrected
   - Corrected light rays
   - IS lens group shifts downward

Source: Canon red book
Image stabilization

Figure-54  EF70-200mm f/2.8L IS USM Image Stabilizer System

source: canon red book
Image stabilization

source: canon red book
1000mm, 1/100s, monopod, IS
Different versions

- Canon, Nikon: in the lens
- Konica/Minolta/Sony: move sensor
Special lenses
Some special lenses

• Mirror lenses
• Tilt-shift lenses
• Macro lenses
  – Why sharpness is always great (thanks Gauss)
  – Why you lose light
catadioptric (mirror)

500mm vivitar ($100)
500mm Canon (5k)
Mirror lens
Links

- http://www.dpreview.com/learn/?/key=chromatic+aberration
- http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/aberrcon.html#c1