Optics 101
for non-optical engineers

Huntington Camera Club

Stuart W. Singer

Schneider OPTICS

B+W FILTER

Schneider KREUZNACH

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Optics 101

Basic Optical Terms

COMMONLY USED UNITS

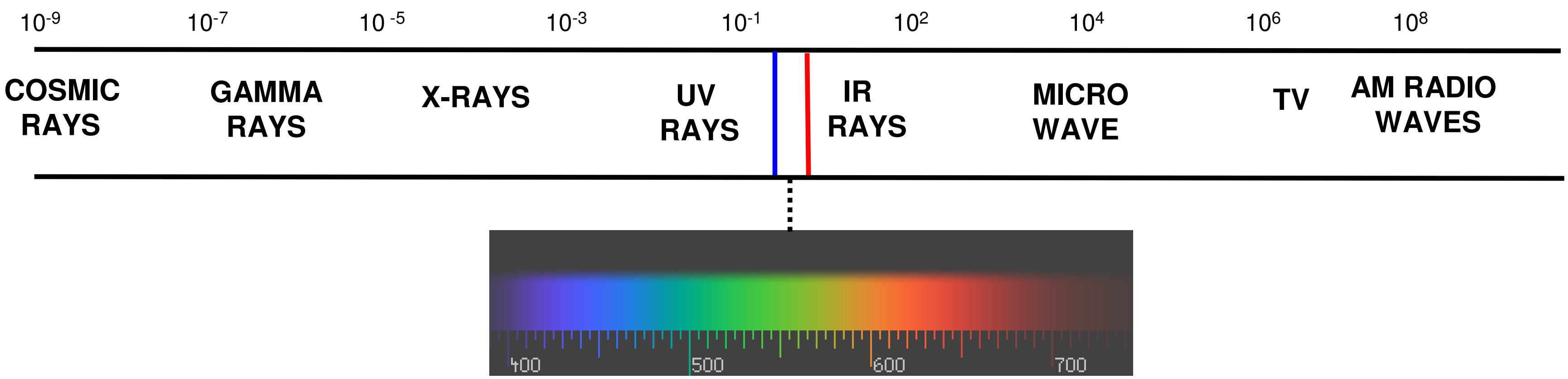
Centimeters =	10^{-2} meter	cm
Millimeters =	10^{-3} meter	mm
Micrometers =	10^{-6} meter	µm
Micron =	10^{-6} meter	µm
Millimicron =	10^{-9} meter	mµ
Nanometer =	10^{-9} meter	nm
Angstrom =	10^{-10} meter	Å
Inch =	25.4mm	In
Millimeter =	0.03937in	mm
Furlong =	201.168 meter	

Basic Optical Terms / Definitions

Light = Electromagnetic radiation detectable by the Human eye , ranging in wavelength from about 400nm to 700nm (1 nanometer = 1 x 10^{-9} meters)

Electromagnetic Spectrum

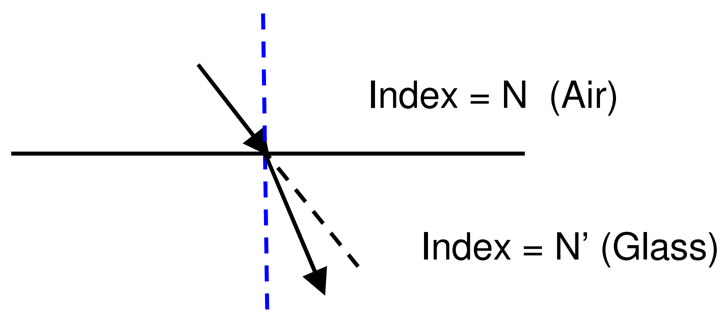
WAVE LENGTHS IN MICROMETERS



VISIBLE SPECTRUM (nanometers)

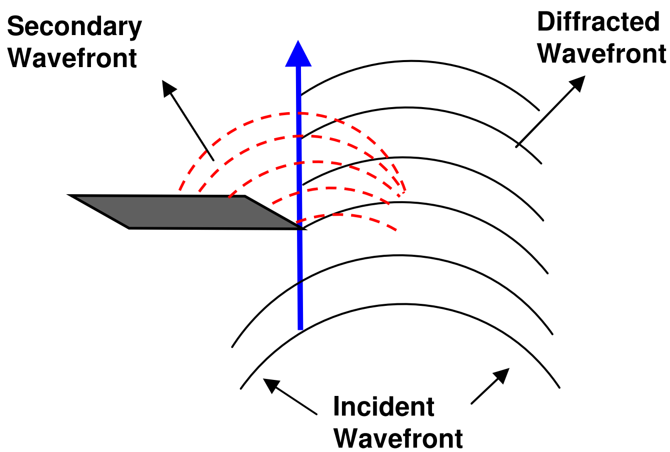
Basic Optical Terms / Definitions

Refraction = The bending of oblique incident rays as they pass from a medium having one refractive index into a medium with a different refractive index



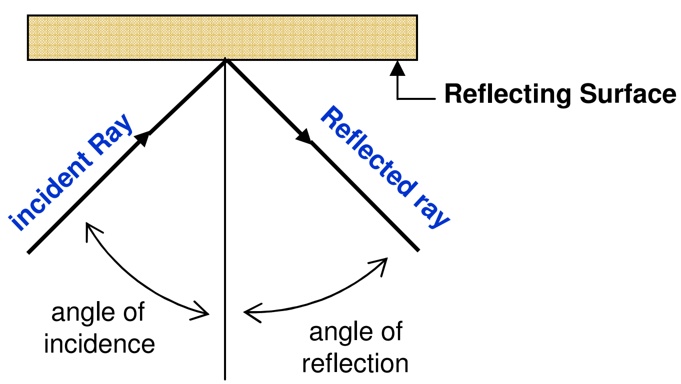
Basic Optical Terms / Definitions

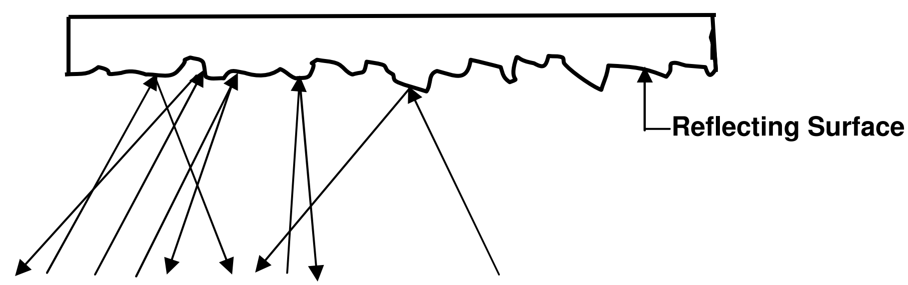
Diffraction = **As a wavefront of light passes by an opaque edge or through an opening, secondary weaker wavefronts are generated. These secondary wavefronts will interfere with the primary wavefront as well as each other to form various diffraction patterns.**



Basic Optical Terms /Definitions

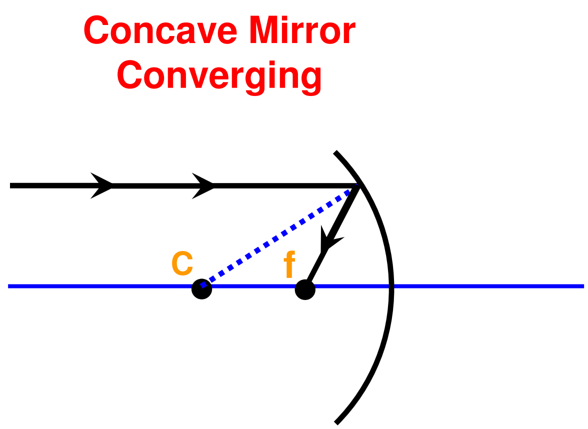
Reflection = Return of radiation by a surface, without change in wavelength. The reflection may be specular, from a smooth surface; diffuse, from a rough surface surface or from within the medium.

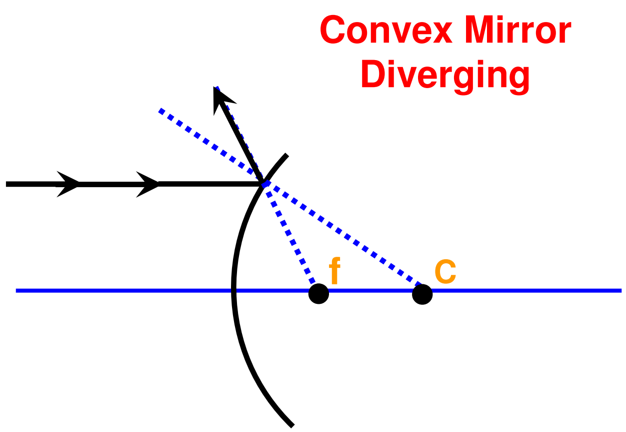




Diffuse Reflection

Powered Mirror(s)

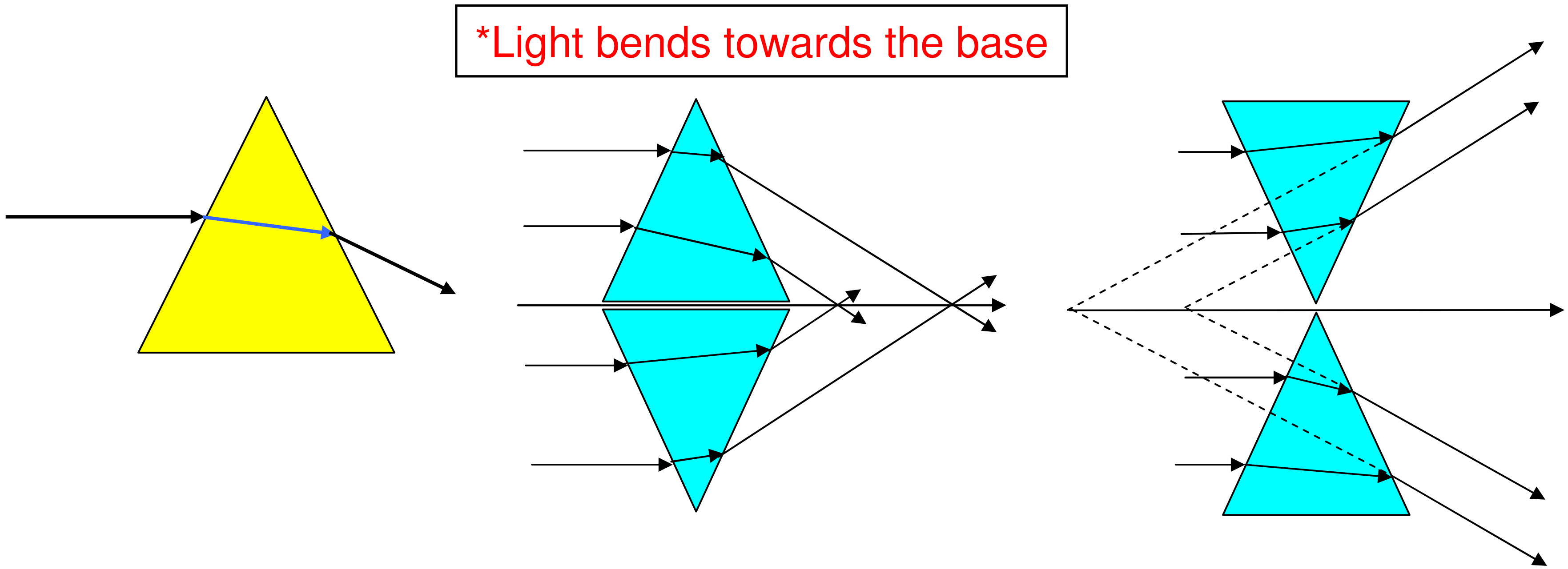


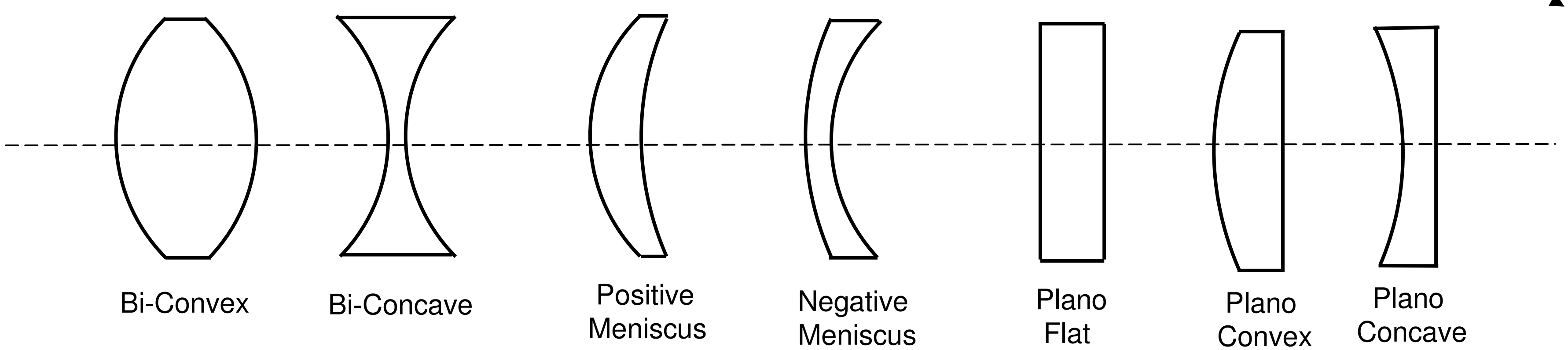


Concave Mirror: is the equivalent of a positive converging element and forms a real image of distant objects

Convex Mirror: forms a virtual image and is equivalent to a negative element

Refraction / Shapes





Optics 101

Lens Design Parameters

Lens Design Considerations

A lens is mainly used to reproduce an object to an image and it is the goal of the lens designer (Optical Engineer) to design a lens to form a Great Image

The following items are taken into careful consideration during the lens design process.

Glass Properties

Index of Refraction = The ratio of the velocity of light in a vacuum to the velocity of light in a refractive material for a given wavelength.

Transmission = The conduction of radiant energy through a medium. Often Denotes the percentage of energy passing through an element or system relative to the amount that entered.

$\Delta n/\Delta t$ = Temperature coefficients of refractive index (change of index of refraction of glass with respect to a change in temperature.

Abbe Constant (V-Value) = The constant of an optical medium that describes the ratio of its refractivity to it dispersion. A high V-Value indicates more nearly equal refraction at all wavelengths

Glass Dispersion = How a particular glass varies in refractive index with respect to wavelength. Often referred to by the name "Abbe Value".

A large Abbe Value = low Dispersion Glass (glass that does not change much in regards to its index of refraction with wavelength change.

Optical Definitions

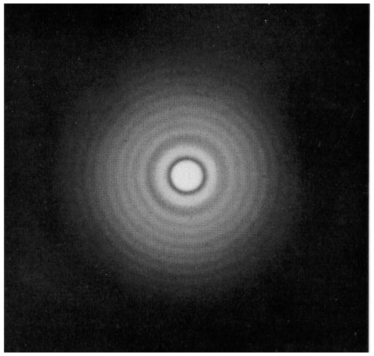
Blur Circle = The image formed by a lens on its focal surface (image plane) of a point source object. The size of the blur circle will dictated by the precision of the lens and the state of focus; The blur can be caused by aberrations in the lens, defocusing and manufacturing defects

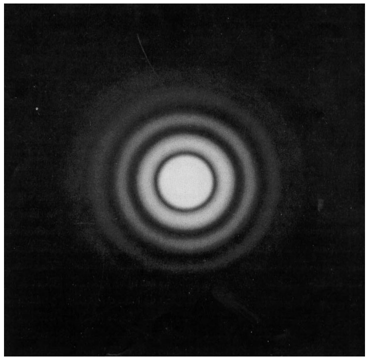
Circle of Confusion = The image of a point source that appears as a circle of finite diameter because of defocusing or the aberrations inherent in the lens design or manufacturing quality

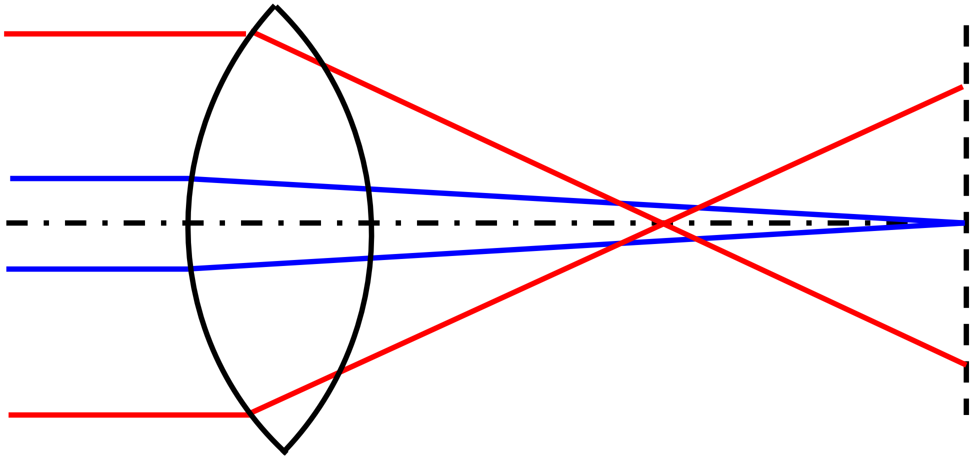
Airy Disk = The central peak (including everything interior to the first zero or dark ring) of the focal diffraction pattern of a uniformly irradiated, aberration-free circular optical system (Lens)

Glass Dispersion = How a particular glass varies in refractive index with respect to wavelength. Often referred to by the name "Abbe Value". A large Abbe Value = low Dispersion Glass (glass that does not change much in regards to its index of refraction with wavelength change.

Spherical Aberration







Spherical Aberration can be defined as the variation of focus with aperture.

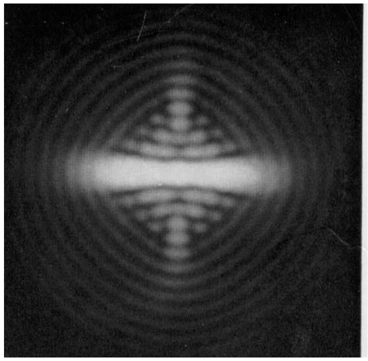
Spherical Example

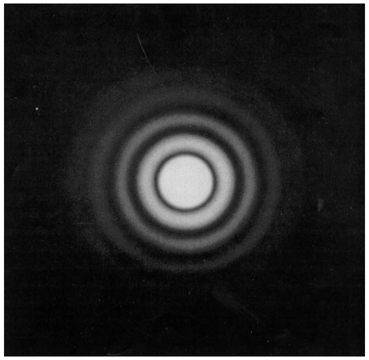
No Spherical Aberration

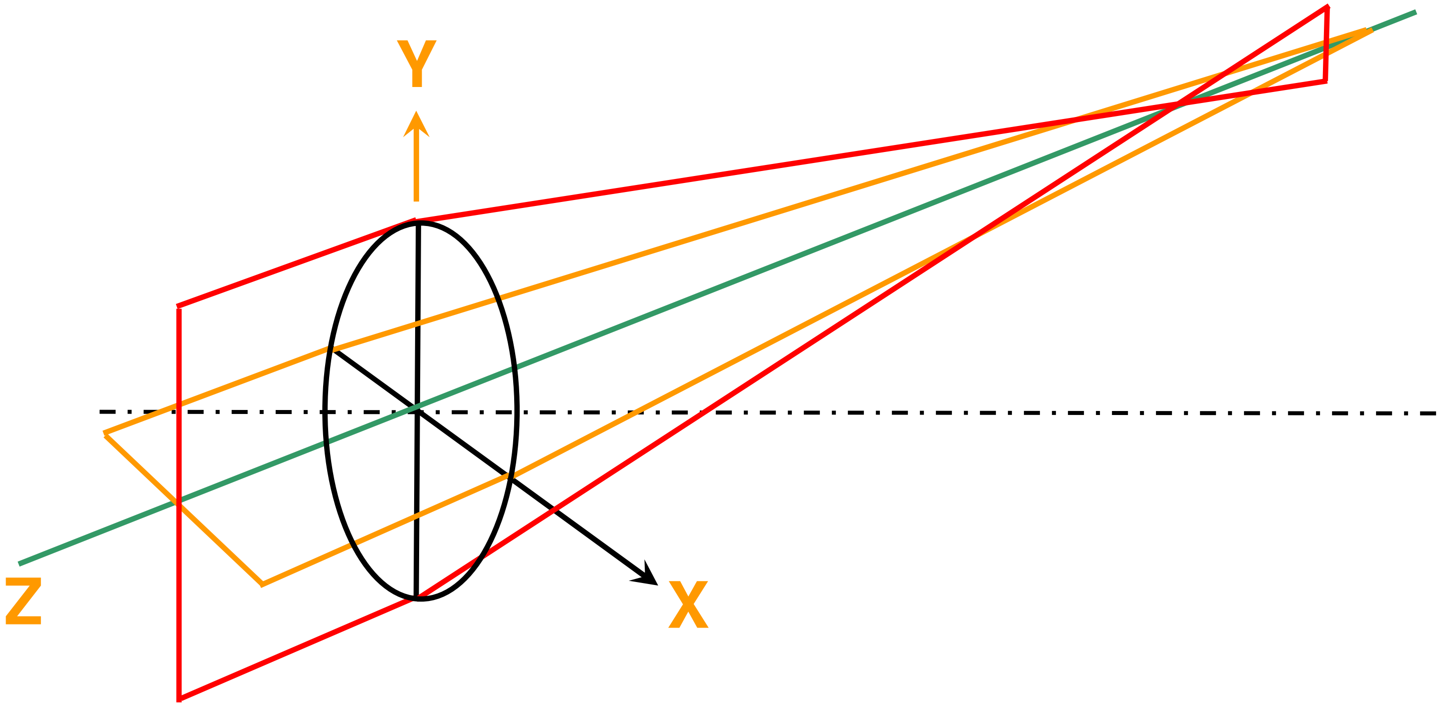
With Spherical Aberration

Astigmatism

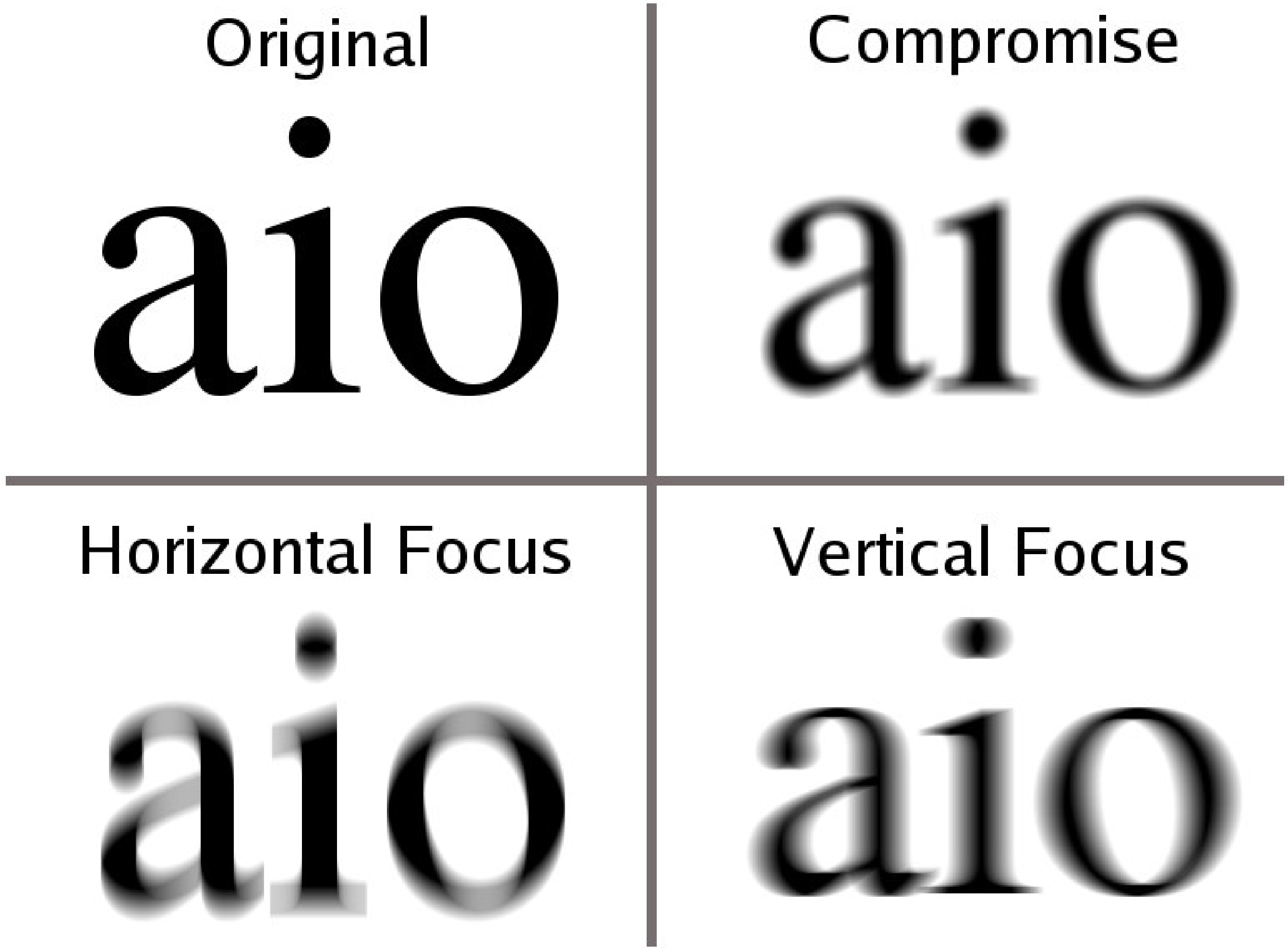
An Astigmatic Image Results When Light In One Plane is Focused Differently From Light In Another Plane





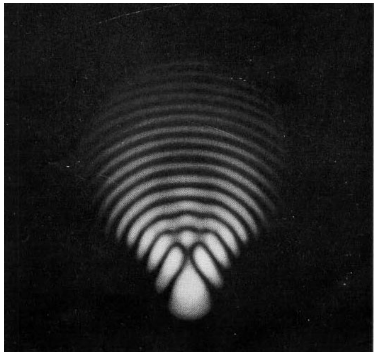


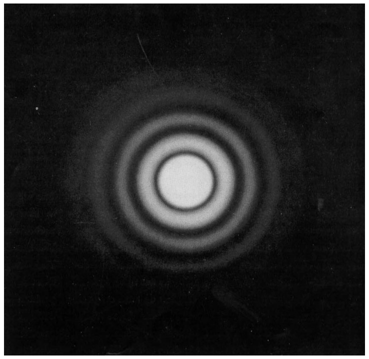
Astigmatism Exp.

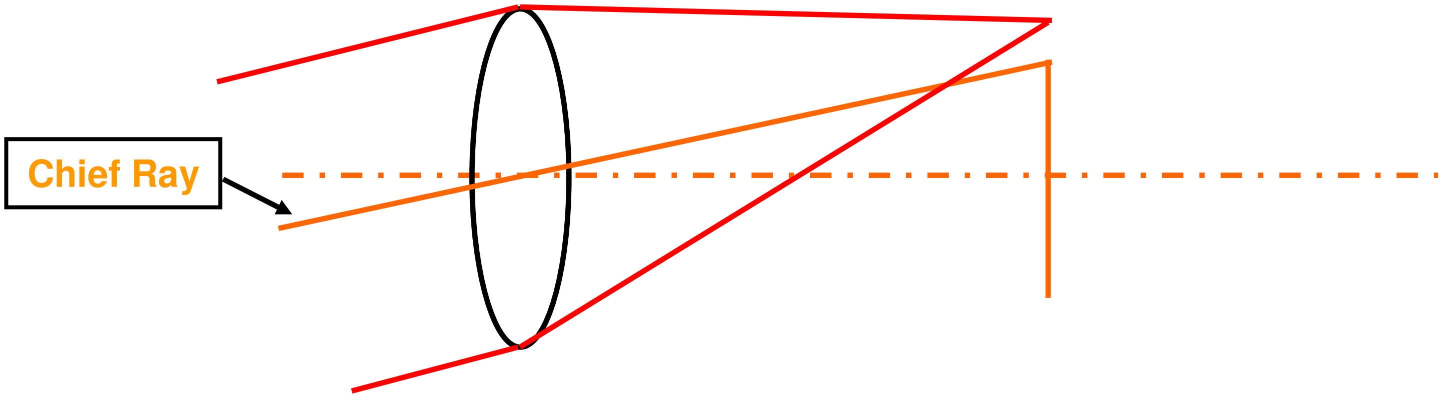


Coma

Coma: can be defined as the variation of magnification with aperture.







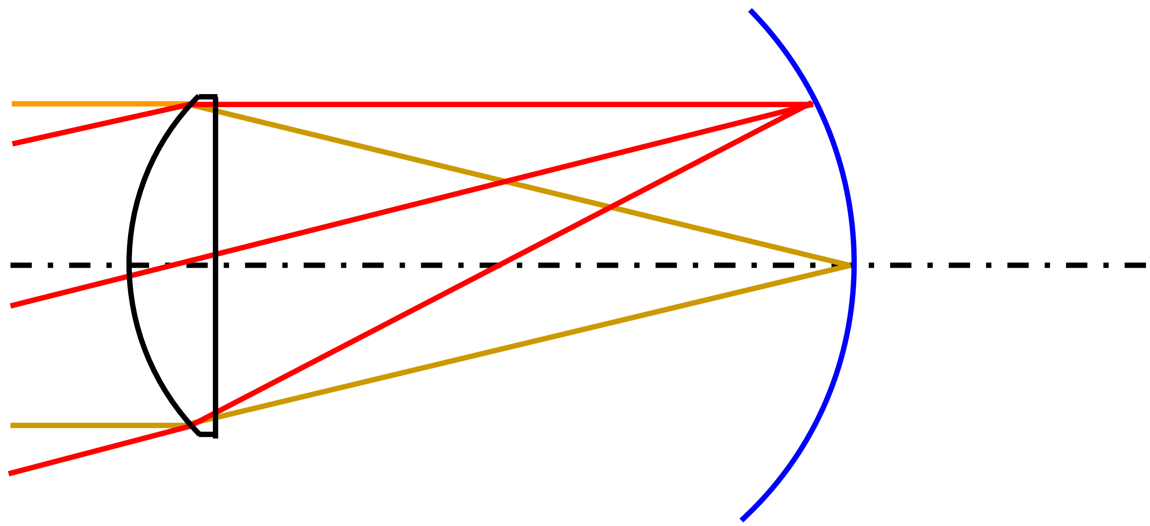
Coma Exp.

No Coma

With Coma

Field Curvature

The image is formed on a curved surface called the **"Petzval"** Surface

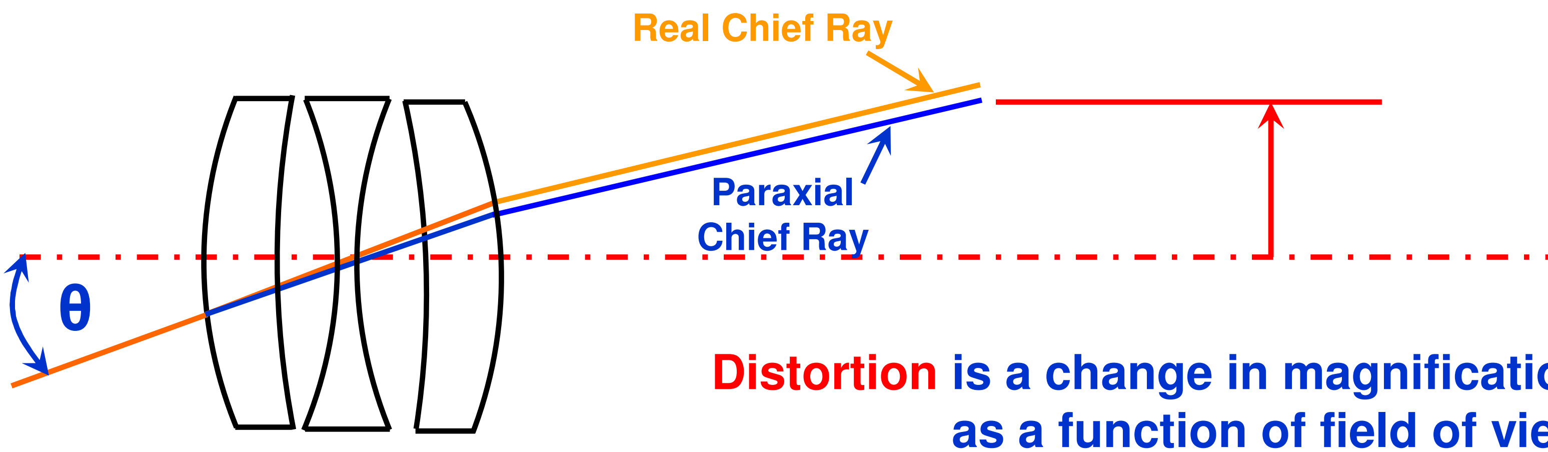


Field Curvature Exp.

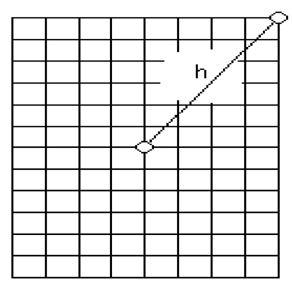
No Field Curvature

With Field Curvature

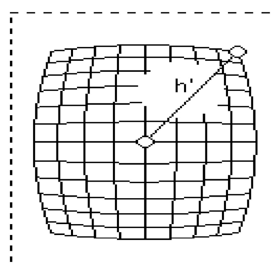
Geometric Distortion



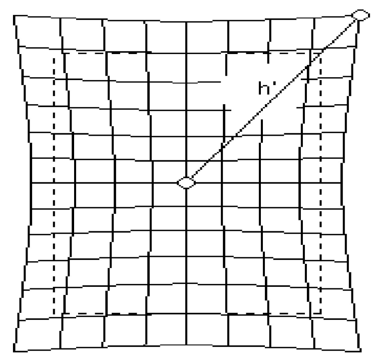
Distortion is a change in magnification as a function of field of view



Zero Distortion



Negative or Barrel



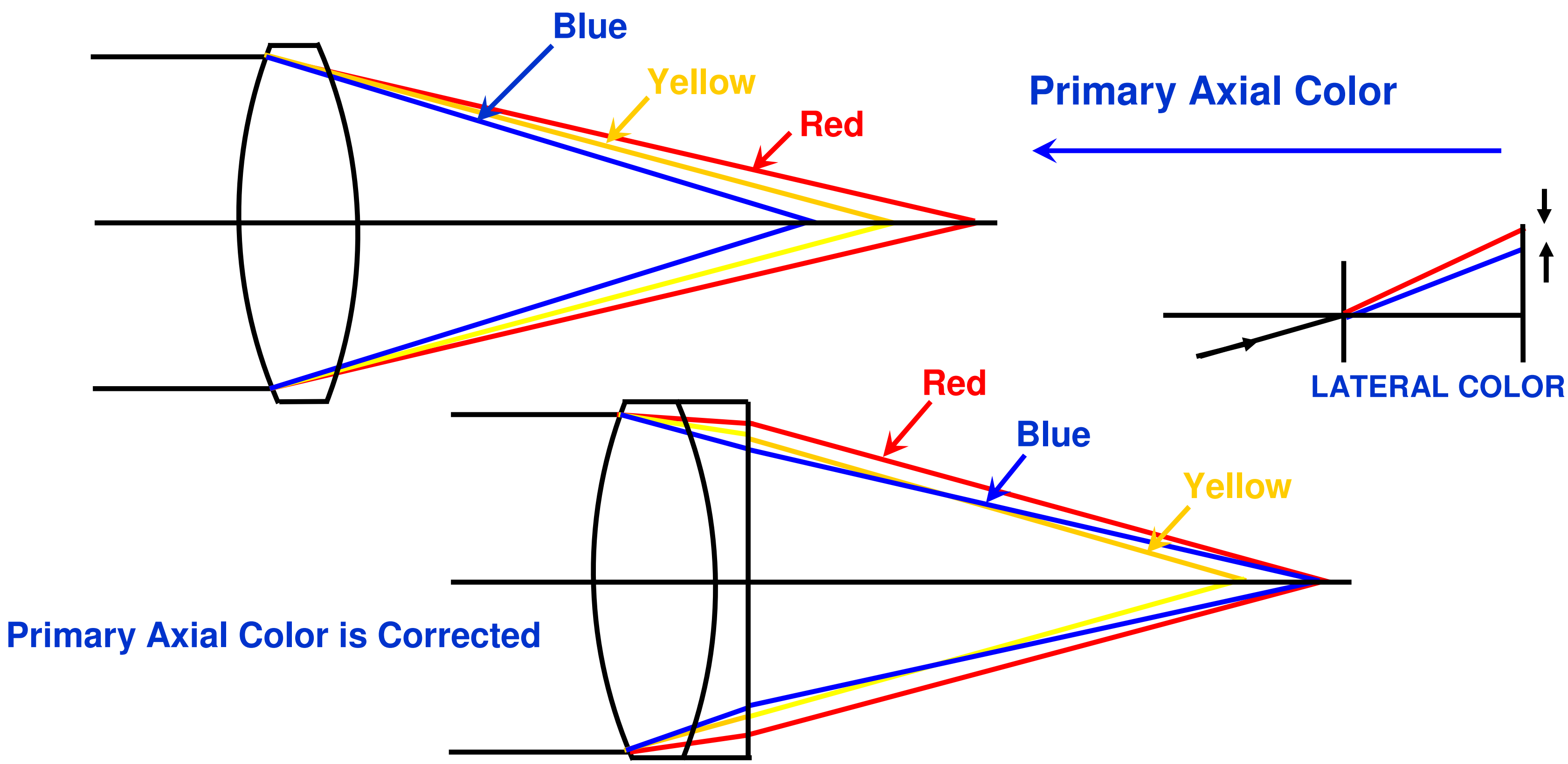
Positive or Pincushion

Geometric Distortion Exp.

No Geometric Distortion

- 40% Geometric Distortion

Axial Chromatic (Longitudinal)



Chromatic Exp.

No Chromatic Aberration

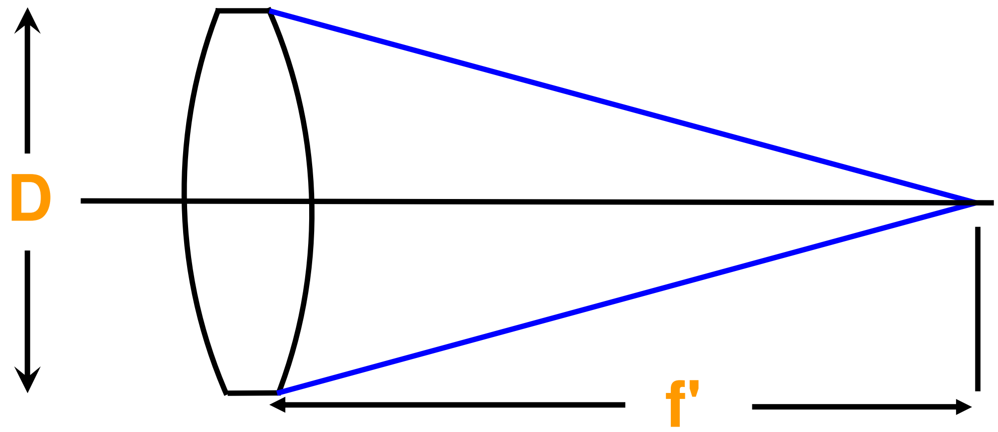
With Lateral Color

Optics 101

f/numbers

F-Number (f/#)

f/# =The ratio of the equivalent focal length of a lens to the diameter of its entrance pupil



f/# = f' / D

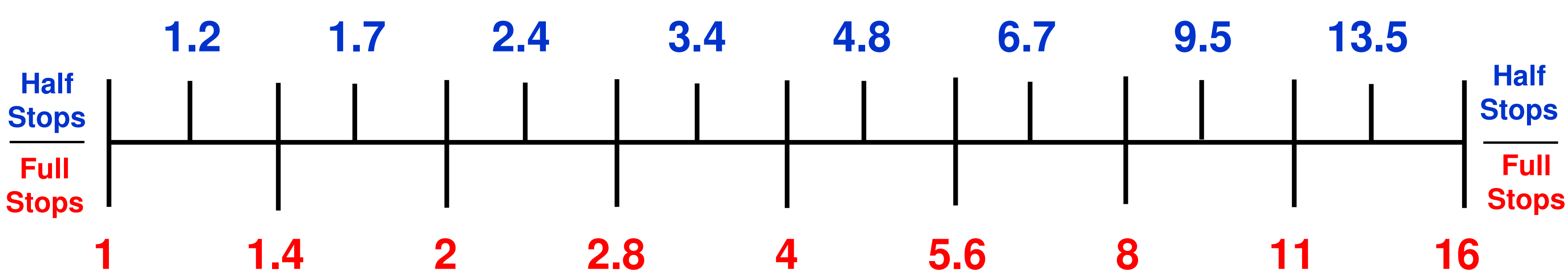
Ex. Focal Length = 50mm Diameter = 50mm f/# = 50/50 = f/1.0	Ex. Focal Length = 50mm Diameter = 25mm f/# = 50/25 = f/2.0

F-Numbers cont.

- Increasing the aperture one full stop doubles the amount of light transmitted by the lens
- Reducing the aperture one full stop halves the amount of light transmitted by the lens

• Lowering the f/number = More Light

• Increasing the f/number = Less Light



Full Stops (cont.): 16, 22, 32, 45, 64, 90

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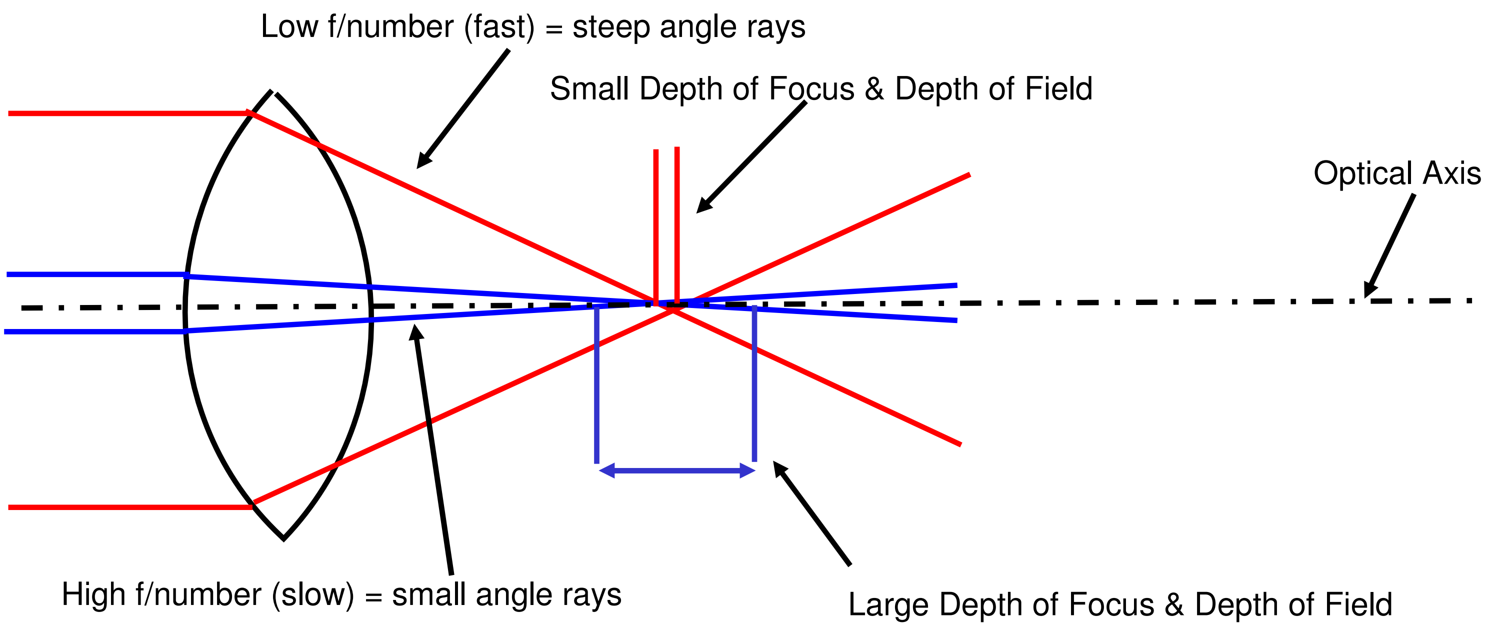
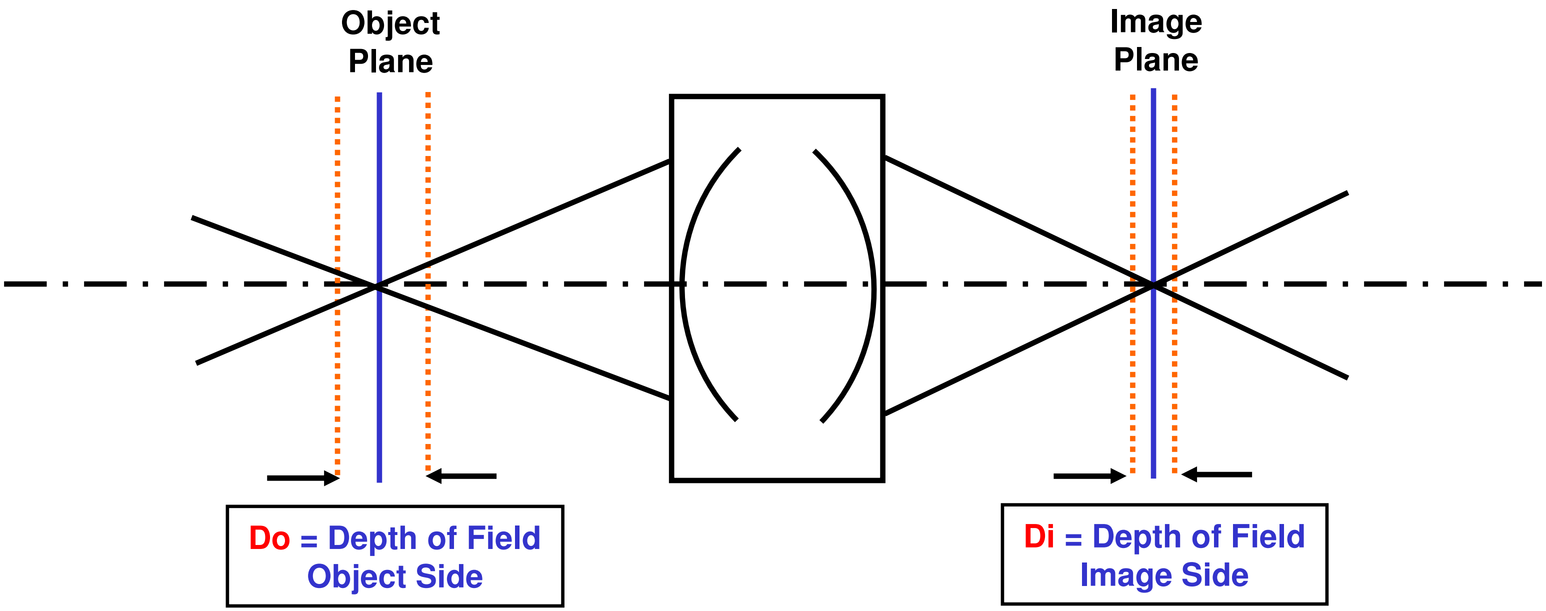
Depth of Field & Hyperfocal Distance

f/number & Depth of Focus/Field

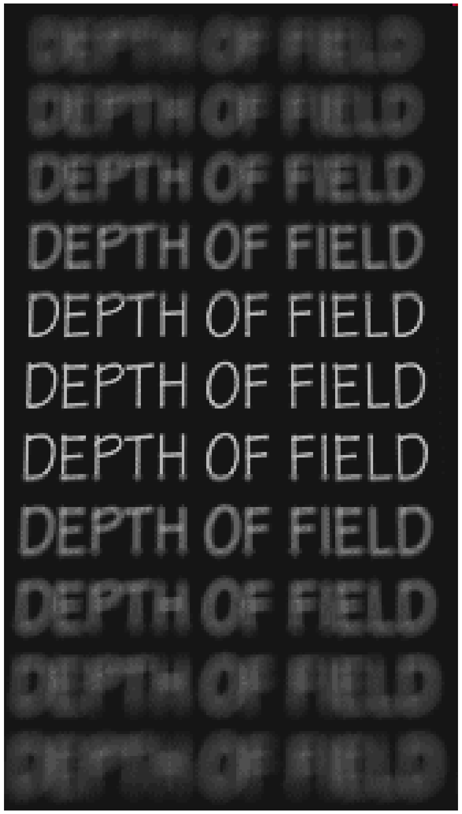


Depth of Focus / Field Related



$$Di = (\beta')^2 \times Do$$

Depth of Field Cont.



Picture from www.cambridgeincolur.com

Depth of Field exp.

1) Aperture, 2) Focal length, and 3) the distance to the subject.

f/1.4

f/5.6

f/16

Pictures from: www.photoaxe.com

Depth of Field Chart (35mm film)

DEPTH - OF - FIELD

BLUR CIR (mm)	FL (mm)
0.033	50

Format	8 x 10	5 x 7	4 x 5	60 x 90	35mm
Blur	0.200	0.140	0.100	0.075	0.033

		f/# 1.4	f/# 2.0	f/# 2.8	f/# 4.0	f/# 5.6	f/# 8.0	f/# 11.0	f/# 16.0	f/# 22.0
Hyperfocal Distance	NEAR (ft)	177.53	124.27	88.77	62.14	44.38	31.07	22.60	15.53	11.30
Focus Distance (feet)										
200	FAR (ft)	∞	∞	∞	∞	∞	∞	∞	∞	∞
	NEAR (ft)	94.05	76.65	61.48	47.41	36.32	26.89	20.30	14.41	10.69
150	FAR (ft)	967.16	∞	∞	∞	∞	∞	∞	∞	∞
	NEAR (ft)	81.30	67.97	55.77	43.94	34.25	25.74	19.64	14.08	10.51
100	FAR (ft)	228.98	511.96	∞	∞	∞	∞	∞	∞	∞
	NEAR (ft)	63.97	55.41	47.02	38.32	30.74	23.70	18.43	13.45	10.15
75	FAR (ft)	129.86	189.16	483.58	∞	∞	∞	∞	∞	∞
	NEAR (ft)	52.73	46.77	40.65	33.98	27.88	21.97	17.36	12.87	9.82
50	FAR (ft)	69.60	83.66	114.49	255.98	∞	∞	∞	∞	∞
	NEAR (ft)	39.01	35.65	31.98	27.71	23.51	19.16	15.56	11.85	9.22
30	FAR (ft)	36.10	39.55	45.31	58.01	92.57	872.30	∞	∞	∞
	NEAR (ft)	25.66	24.17	22.42	20.23	17.90	15.26	12.89	10.23	8.21
25	FAR (ft)	29.10	31.30	34.80	41.83	57.24	127.99	∞	∞	∞
	NEAR (ft)	21.91	20.81	19.51	17.83	15.99	13.85	11.87	9.58	7.78
20	FAR (ft)	22.54	23.94	25.82	29.49	38.40	56.14	174.13	∞	∞
	NEAR (ft)	17.98	17.23	16.32	15.13	13.79	12.17	10.61	8.74	7.22
15	FAR (ft)	16.38	17.06	18.05	19.77	22.66	29.00	44.62	436.15	∞
	NEAR (ft)	13.83	13.38	12.83	12.09	11.21	10.12	9.02	7.63	6.44
10	FAR (ft)	10.60	10.88	11.27	11.92	12.91	14.75	17.94	28.07	87.06
	NEAR (ft)	9.47	9.26	8.99	8.61	8.16	7.57	6.93	6.08	5.30
5	FAR (ft)	5.14	5.21	5.30	5.44	5.63	5.96	6.42	7.37	8.97
	NEAR (ft)	4.86	4.81	4.73	4.63	4.49	4.31	4.09	3.78	3.47

Depth of Field Chart (Digital Camera)

DEPTH - OF - FIELD

BLUR CIR (mm)	FL (mm)
0.004	50

Format	8 x 10	5 x 7	4 x 5	60 x 90	35mm
Blur	0.200	0.140	0.100	0.075	0.033

		f/# 1.4	f/# 2.0	f/# 2.8	f/# 4.0	f/# 5.6	f/# 8.0	f/# 11.0	f/# 16.0	f/# 22.0
Hyperfocal Distance	NEAR (ft)	1464.66	1025.26	732.33	512.63	366.16	256.32	186.41	128.16	93.21
Focus Distance (feet)										
200	FAR (ft)	231.63	249.47	275.14	327.95	440.73	910.29	∞	∞	∞
	NEAR (ft)	175.97	167.35	157.10	143.87	129.35	112.34	96.48	78.11	63.59
150	FAR (ft)	167.11	175.71	188.64	212.05	254.09	361.64	767.96	∞	∞
	NEAR (ft)	136.07	130.86	124.50	116.04	106.41	94.62	83.12	69.11	57.49
100	FAR (ft)	107.33	110.81	115.81	124.23	137.57	163.97	215.73	455.14	∞
	NEAR (ft)	93.61	91.11	87.99	83.69	78.55	71.93	65.09	56.17	48.24
75	FAR (ft)	79.05	80.92	83.56	87.85	94.32	106.02	125.49	180.82	383.97
	NEAR (ft)	71.35	69.89	68.03	65.43	62.25	58.02	53.48	47.31	41.56
50	FAR (ft)	51.77	52.56	53.66	55.40	57.91	62.12	68.33	81.99	107.86
	NEAR (ft)	48.35	47.67	46.80	45.56	43.99	41.84	39.43	35.97	32.54
30	FAR (ft)	30.63	30.90	31.28	31.86	32.69	33.98	35.75	39.17	44.24
	NEAR (ft)	29.40	29.15	28.82	28.34	27.73	26.86	25.84	24.31	22.70
25	FAR (ft)	25.43	25.62	25.88	26.29	26.83	27.70	28.87	31.06	34.16
	NEAR (ft)	24.58	24.40	24.17	23.84	23.40	22.78	22.04	20.92	19.71
20	FAR (ft)	20.28	20.40	20.56	20.81	21.16	21.69	22.40	23.70	25.46
	NEAR (ft)	19.73	19.62	19.47	19.25	18.96	18.55	18.06	17.30	16.47
15	FAR (ft)	15.16	15.22	15.31	15.45	15.64	15.93	16.31	16.99	17.88
	NEAR (ft)	14.85	14.78	14.70	14.57	14.41	14.17	13.88	13.43	12.92
10	FAR (ft)	10.07	10.10	10.14	10.20	10.28	10.41	10.57	10.85	11.20
	NEAR (ft)	9.93	9.90	9.87	9.81	9.73	9.62	9.49	9.28	9.03
5	FAR (ft)	5.02	5.02	5.03	5.05	5.07	5.10	5.14	5.20	5.28
	NEAR (ft)	4.98	4.98	4.97	4.95	4.93	4.90	4.87	4.81	4.75

Depth of Field Cont.

Distribution of the Depth of Field

Focal Length (mm)	Rear	Front
10	70.2 %	29.8 %
20	60.1 %	39.9 %
50	54.0 %	46.0 %
100	52.0 %	48.0 %
200	51.0 %	49.0 %
400	50.5 %	49.5 %

A wide angle lens provides a more gradually fading DoF behind the focal plane than in front, which is important for traditional landscape photographs. On the other hand, when standing in the same place and focusing on a subject at the same distance, a longer focal length lens will have a shallower depth of field (even though the pictures will show something entirely different).

Data from from www.cambridgeincolur.com

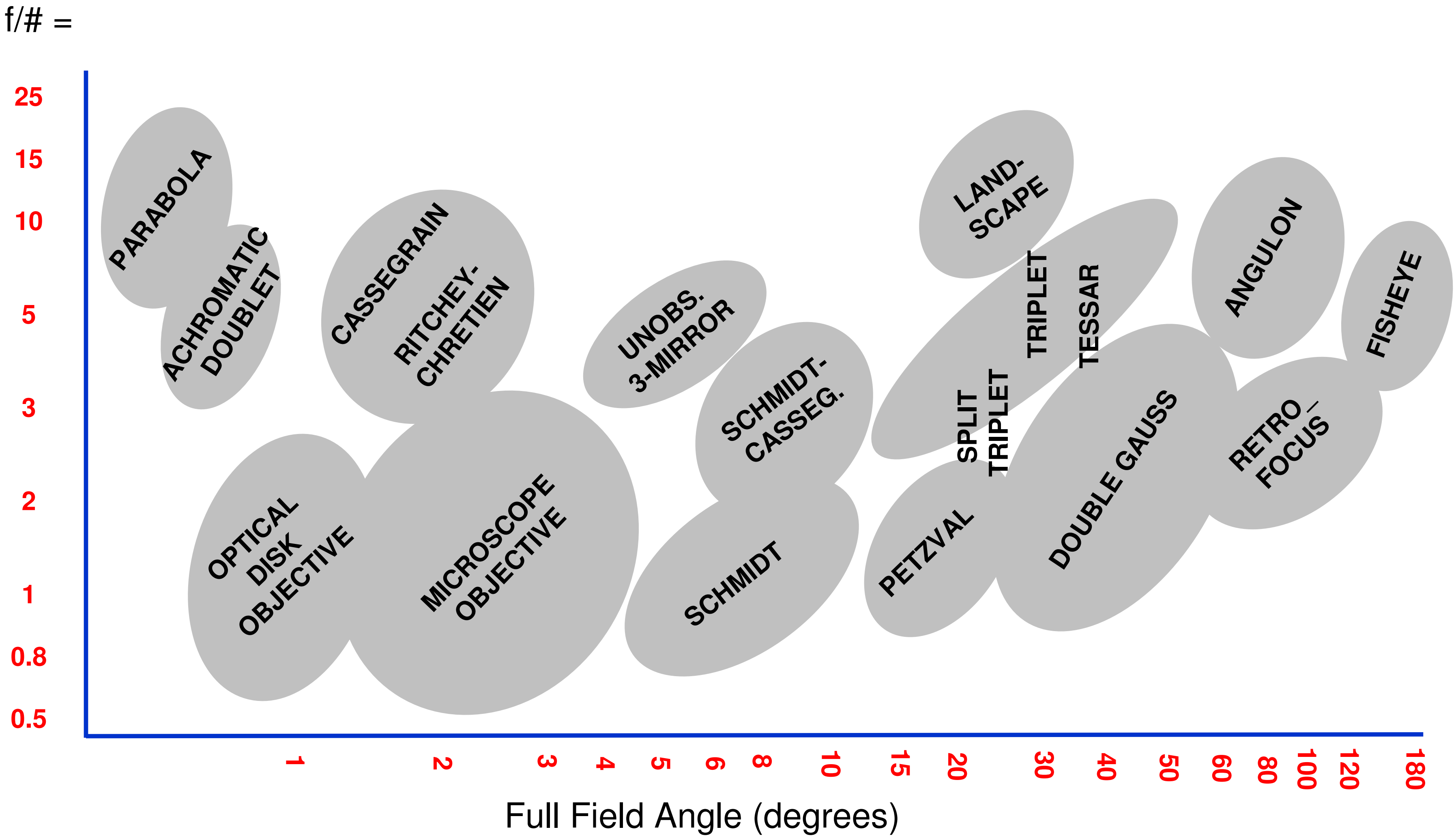
Hyperfocal Distance

The object distance at which a camera must be focused so that the Far Depth of Field just extends to infinity.

Picture from: www.cambridgeincolur.com

Lens Design Types

LENS DESIGN TYPES



OPTICAL DESIGN (Rx)

System/Prescription Data

File : C:\ZEMAX\Samples\Sequential\Objectives\Inverse telephoto lens.zmx
Title: INVERSE TELEPHOTO LENS
Date : TUE AUG 2 2005

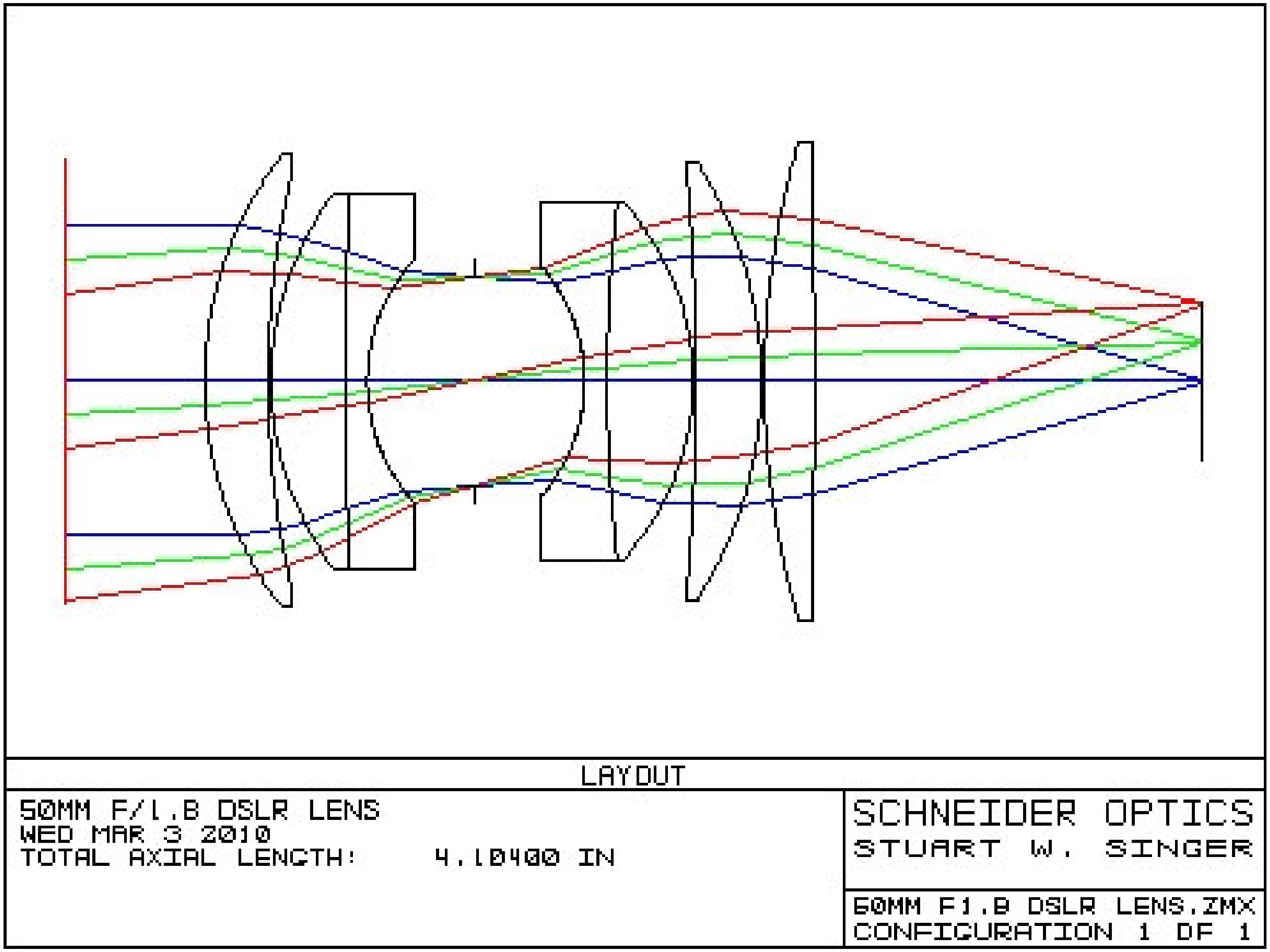
LENS NOTES:

Notes...

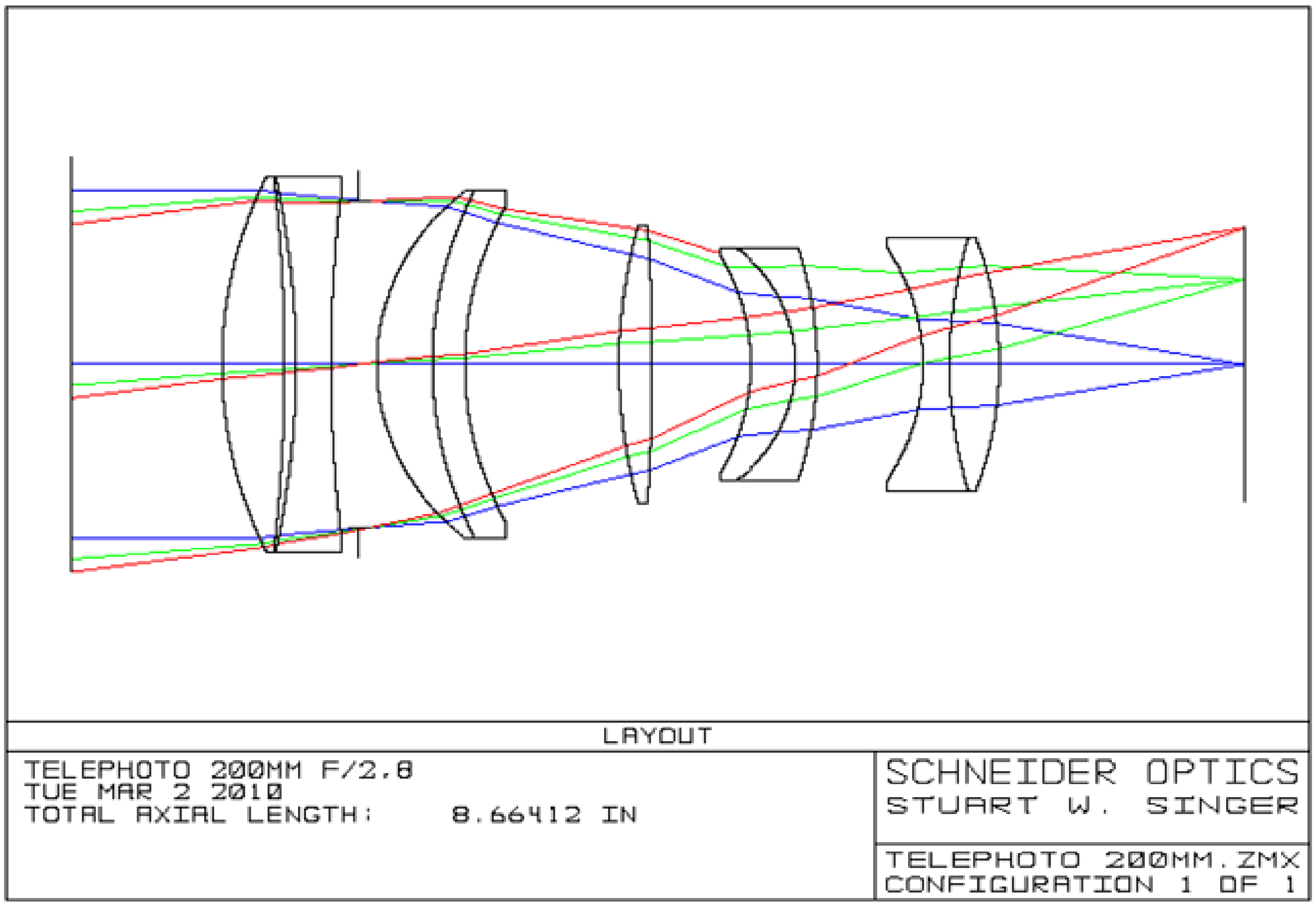
SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	Infinity		0	0
1	STANDARD	1.01143	0.0494	SK10	0.8734301	0
2	STANDARD	0.56468	0.1279		0.7640233	0
3	STANDARD	1.4622	0.048	SK15	0.744307	0
4	STANDARD	0.65261	0.4505		0.6822052	0
5	STANDARD	1.10072	0.1653	BASF2	0.5590828	0
6	STANDARD	-1.88076	0.0053		0.5145576	0
7	STANDARD	0.51351	0.068	FK3	0.444328	0
8	STANDARD	1.7307	0.1197		0.4156509	0
STO	STANDARD	Infinity	0.04		0.33194	0
10	STANDARD	-1.0523	0.0385	SF15	0.3343764	0
11	STANDARD	0.56092	0.0448		0.3365687	0
12	STANDARD	2.19106	0.0319	SF5	0.363637	0
13	STANDARD	1.41283	0.1121	LAKN12	0.3884956	0
14	STANDARD	-0.55599	1.203409		0.4260953	0
IMA	STANDARD	Infinity			1.132149	0

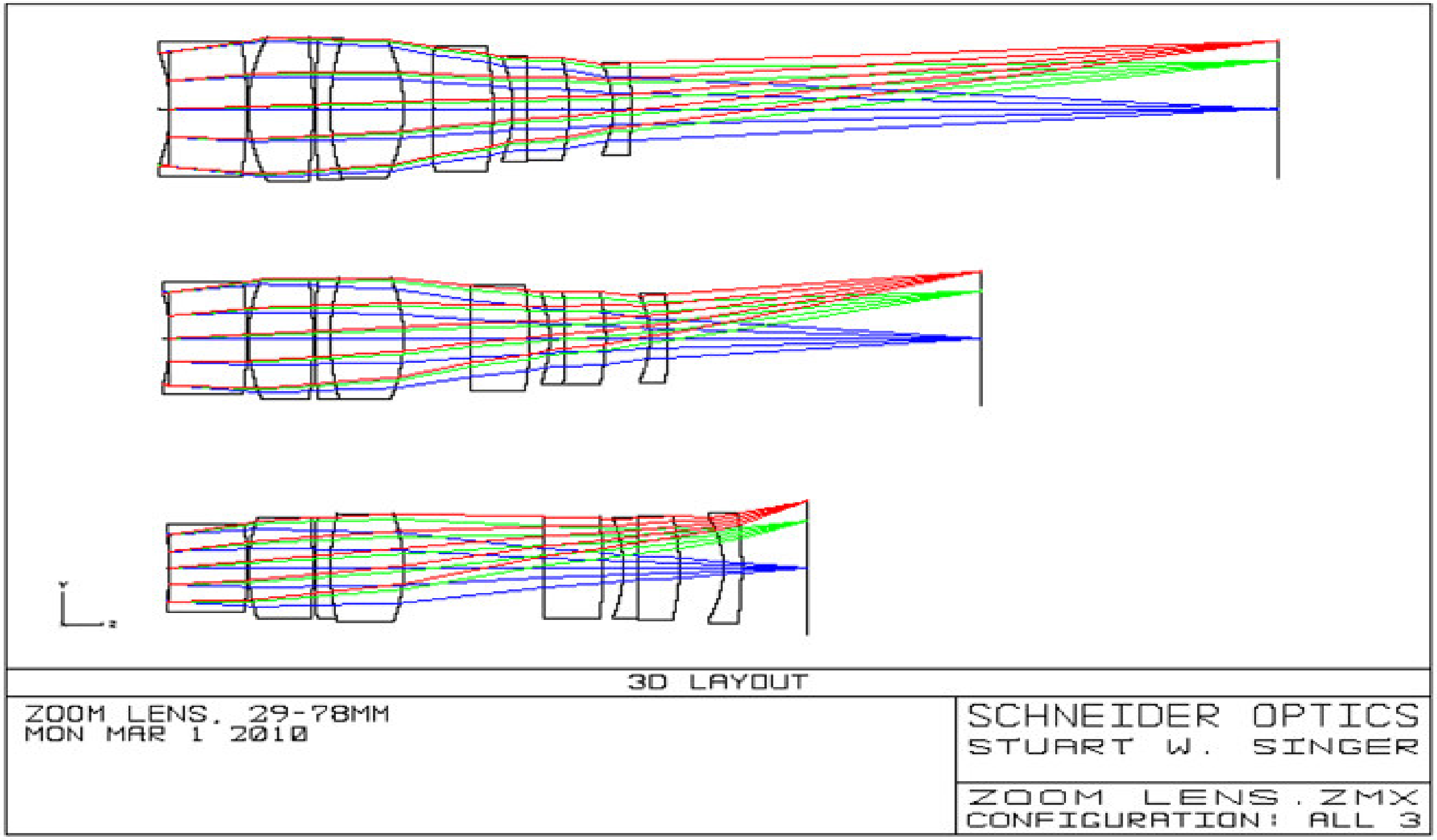
Double Gauss 50mm f/1.8 (Typical SLR/DSLR Lens)



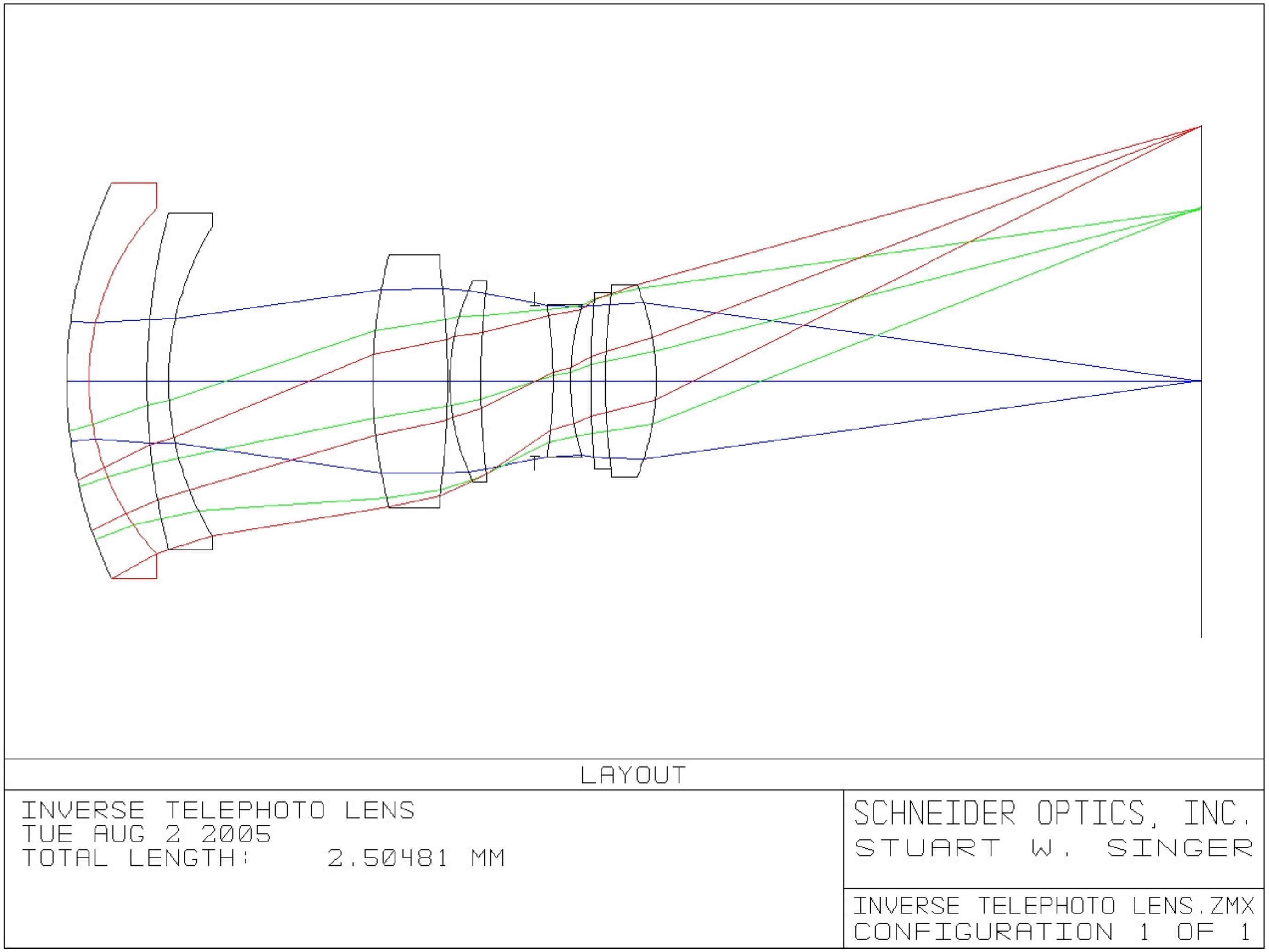
Telephoto Lens Design



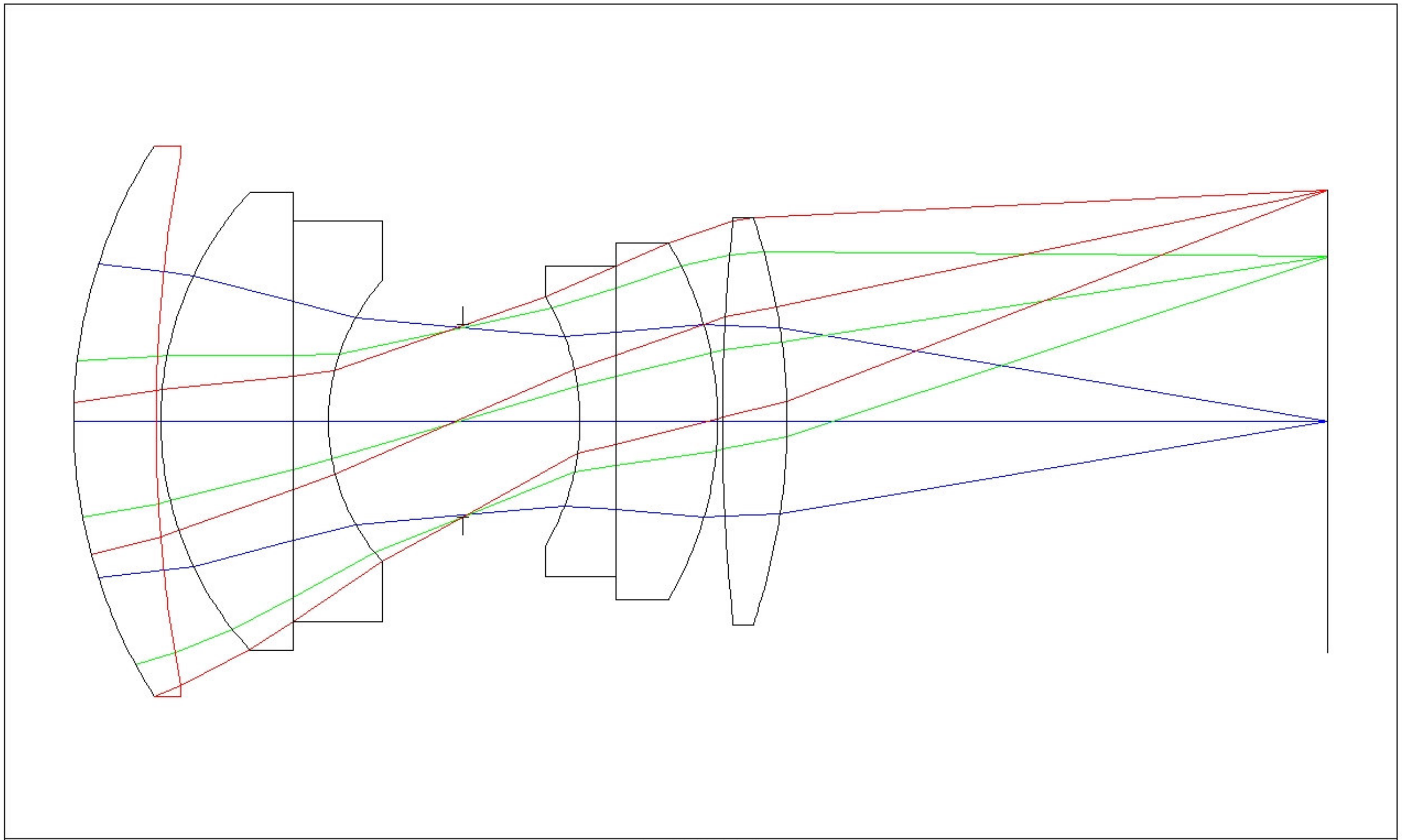
Zoom Lens Design



Design Sample (Inverse Telephoto)

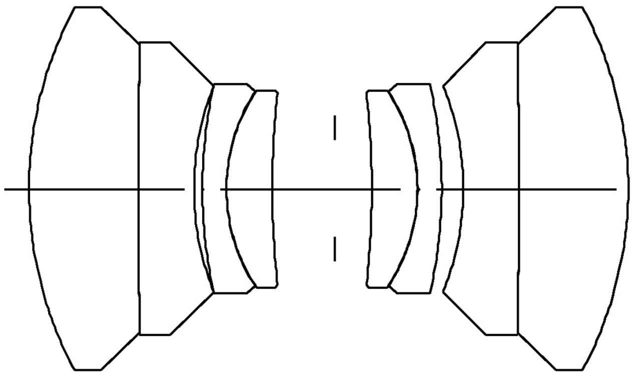


Design Sample (Double Gauss – Macro Lenses)



LAYOUT	
DOUBLE GAUSS TUE AUG 2 2005 TOTAL LENGTH: 132.98842 MM	SCHNEIDER OPTICS, INC. STUART W. SINGER
	DOUBLE GAUSS 28 DEGREE FIELD.ZMX CONFIGURATION 1 OF 1

Macro Lenses

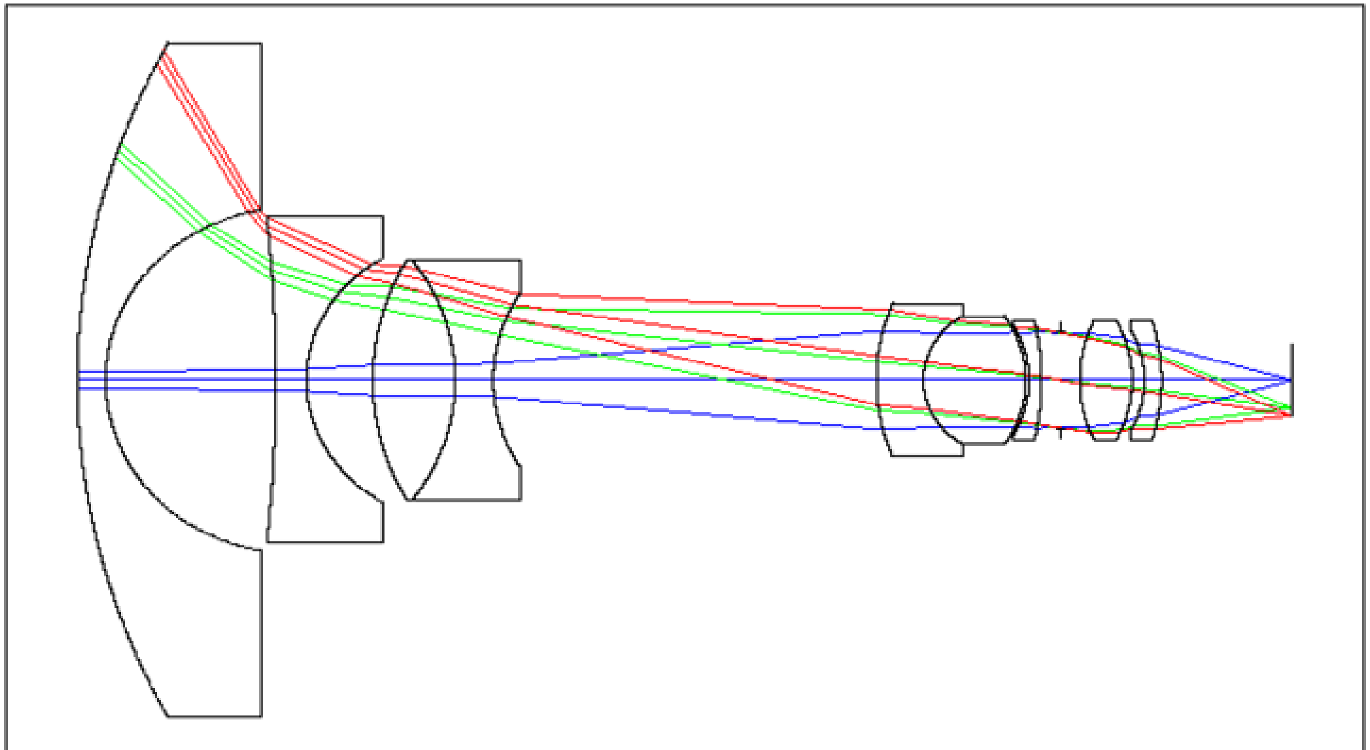


A camera lens, used in macro-imaging, that is designed to produce optimum definition of a subject when it is imaged at a magnification ratio near 1:1
≈ (1:4 to 4:1)

When to use/employ:

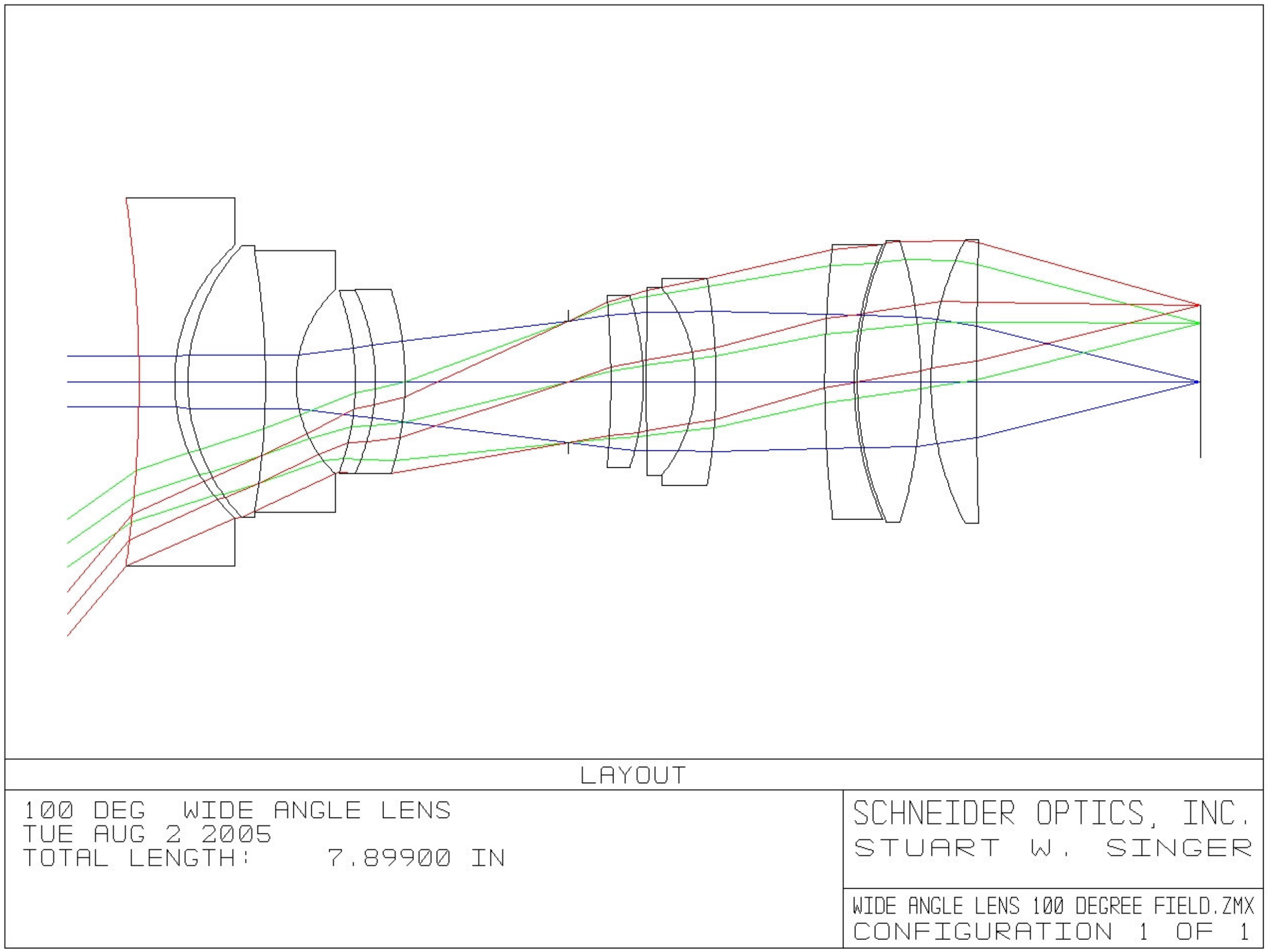
Magnification is near 1:1
MTF drops quickly outside the Magnification region

Design Sample (Wide Angle Fisheye)



LAYOUT	
170 DEG FOV LESN 8MM FOCAL LENGTH F/1.8 THU MAR 4 2010 TOTAL AXIAL LENGTH: 12.13106 IN	SCHNEIDER OPTICS STUART W. SINGER
	170 DEG 8MM.ZMX CONFIGURATION 1 OF 1

Design Sample (Wide Angle)



Filters for Digital Photography

Protection Filter / UV Block

B+W Protection Filter Type 010
The classic among the protection filters blocks the unwanted UV component contained in daylight. The invisible UV light occurs more in pure sea air and in the mountains, and can lead to blur and blue cast. The colorless UV filters are suitable for both analog and digital cameras and ensure more brilliant pictures. The filter can remain permanently on the lens to protect it from dirt and damage.
A high-grade Anti-Reflection coating provides optimum reflection reduction.

Close Up / Macro Attachments (Diopter)

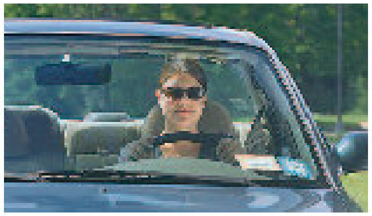
Close-up lenses
Like reading glasses, close-up lenses move the focus range into the close-up zone. The effect increases with the diopter number and the focal length of the lens. For shorter focal lengths in digital photography stronger close-up lenses are therefore recommended.
Close-up and macro lenses are simple aids which are suitable in particular for three-dimensional objects (flowers) and pictorial photography, less for technical reproduction purposes. Sufficient stopping down increases the sharpness and the depth of field. A tripod may be required for longer exposure times.

Without a close-up lens the minimum focus is usually not sufficient

Close-up lenses reduce the minimum focus, producing clear details

Polarizing Filters (Circular)

The standard circular polarizing filter is equally suitable for both film and digital cameras. Linear polarization can falsify exposure of AF metering if beams are split inside the camera (by mirrors or prisms). Circular polarization prevents this, while otherwise retaining the same effect.

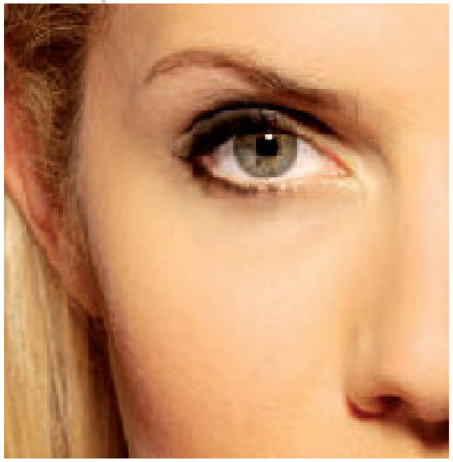


Without Filter

With Filter

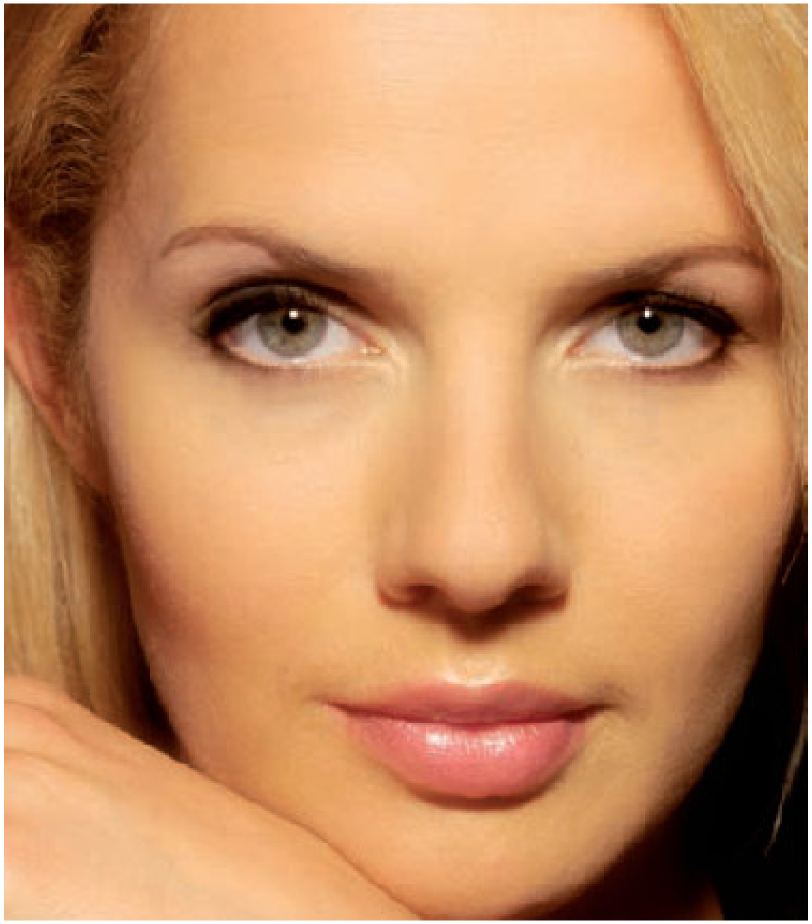
Portraiture (Soft Focus)

The filter delivers sharp pictures which are softly overlaid with unsharpness. Details such as eyelashes do not taper into unsharpness, while skin blemishes are gently covered up. Small mini-lenses are distributed randomly on a precisely plane-parallel glass disc. They scatter the light and overlay the sharp core image with hazy, diffuse halos. This opens up deep shadows, while highlights themselves are hardly blurred, but instead form a shimmering aura in the darker surroundings. Professionals, even in Hollywood films, use these stable glass filters when aiming for perfect beauty shots. The effect cannot be achieved with image-processing software (e.g. Gaussian blur).



Even minimal skin blemishes remain recognizable without the Soft filter

Lip gloss as a hard reflection instead of a soft shimmer



Fine structures such as eyelashes remain recognizable. Skin blemishes, on the other hand, are reduced. Highlights, here the lip gloss, are surrounded by a subtle shimmer

IR Filter

This filter blocks visible light (up to 800 mm) almost completely. It is dark red, almost black. With film IR or IR-sensitive digital cameras it delivers a fantastic wood effect (white leaves) and a typically dark sky. The exposure values vary according to the digital camera model being used and are best determined by experimenting. They are usually in the range of a few seconds.

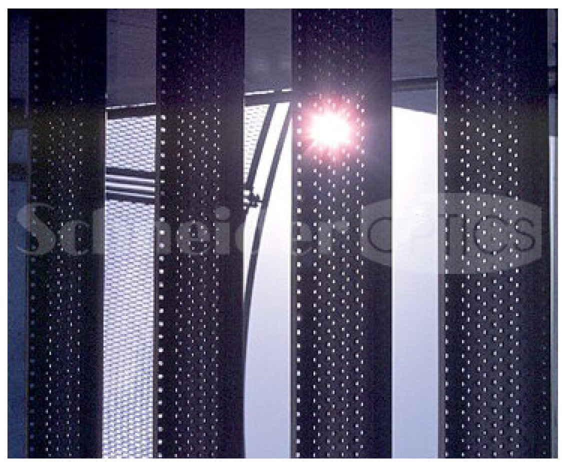
Star Filters (Cross Screen)

Cross Screen filter are made from a clear polished filter that contains precision polished Lines (etched) into the glass. They come in different values ranging from 2x to 8x lines. These filter have to be rotated to 45 degrees With respect to the light source.

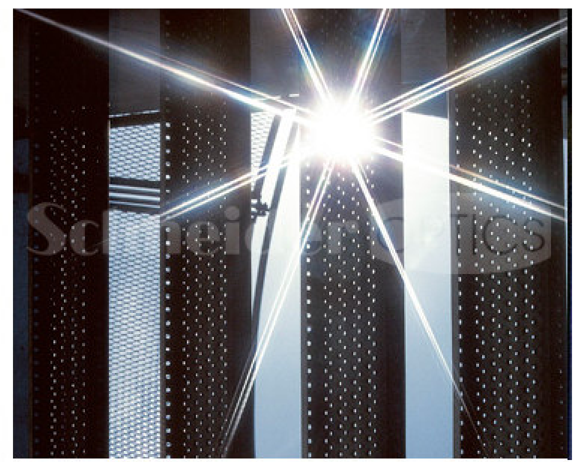
Without Filter

With Filter

With Filter



Without Filter



With Filter

Enhancing Filters

Enhancing filter (made from didymium glass) improves the color saturation of reds, oranges, and earth-tone colors such as rust, brown and amber. The range of colors improved by the enhancing filter makes it popular for use on autumn foliage and brownish-red scenic compositions, such as those found at the Grand Canyon. It is also the filter of choice for intensifying the red in objects such as tomatoes, cherries, strawberries and fire engines.

Without Filter

With Filter

Warming Filter

Warming filters. As the name suggests, these useful items work to remove the bluish cast that can result from cloudy, overcast lighting or shade. Snow has an exceptional ability to pick up this blue cast so it's a good idea to keep a warming filter handy during winter.

Without Filter

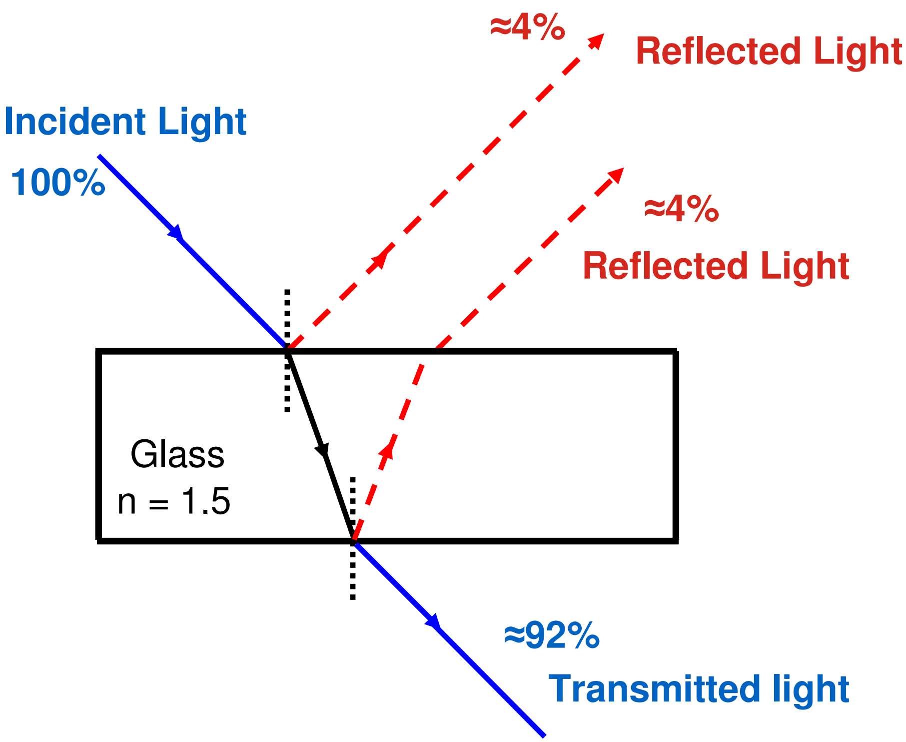
With Filter

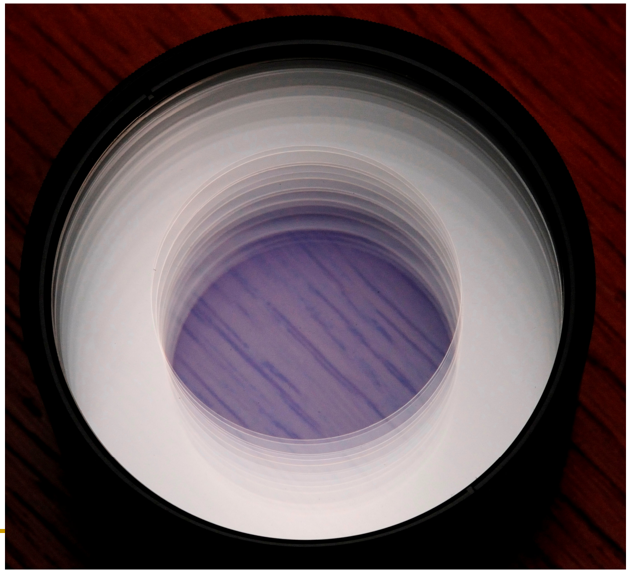
Without Filter

With Filter

Anti-Reflection Coatings & Glare

Anti-Reflection Coatings

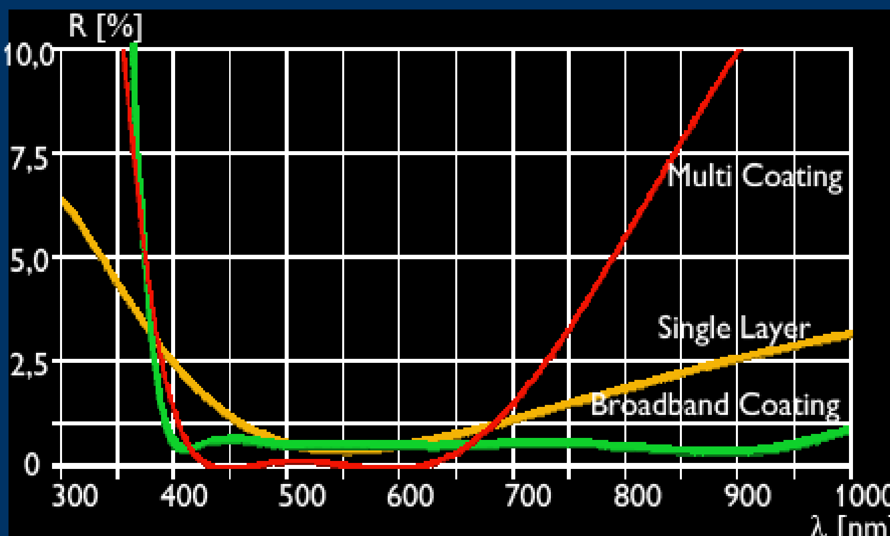




Un-Coated Glass (index of refraction = 1.5) Reflects ≈ 4% per Surface. 92% of light is transmitted. This does not take into account any glass absorption.

Anti-Reflection Coatings

Antireflection Coating



A broadband antireflection coating reduces the amount of stray light for good image quality in the VIS+NIR wavelength range.

Rule of Thumb – uncoated glass reflects ≈ 4% of light per surface (visible light)
- High quality anti-reflection coating reflect < 1% per surface (visible light)

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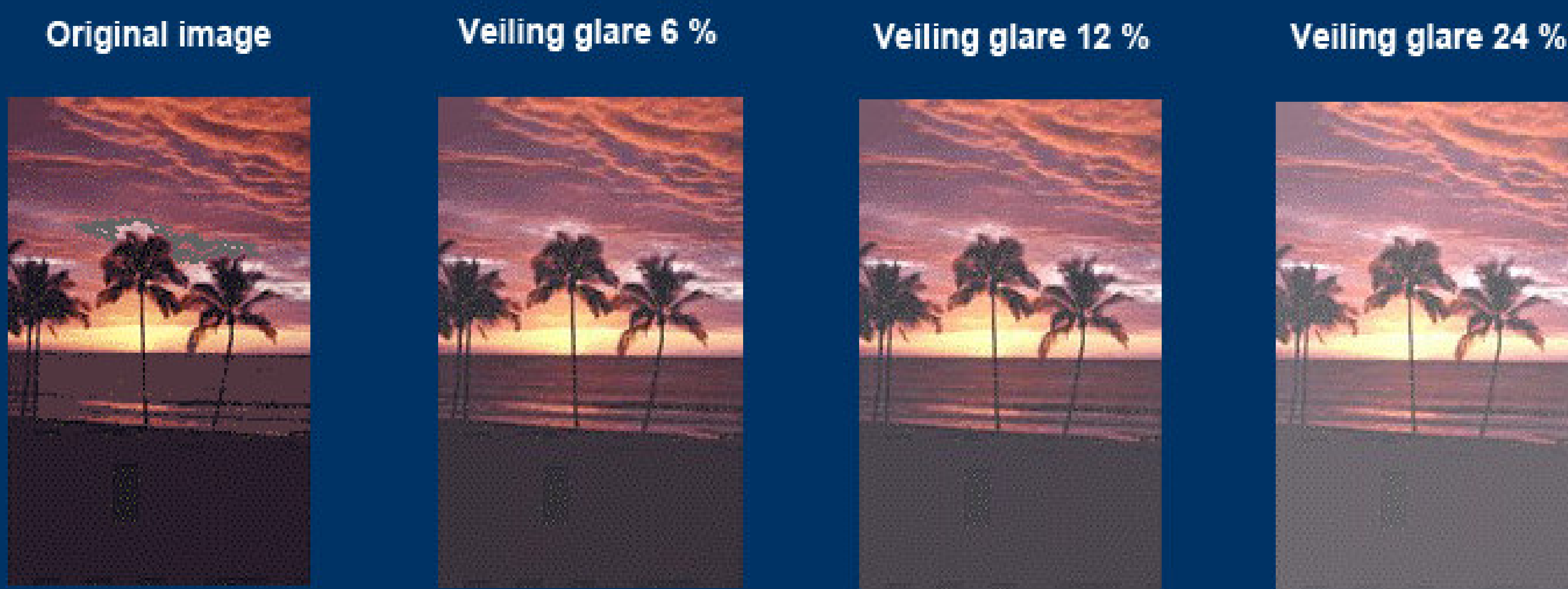
Veiling Glare

veiling glare:

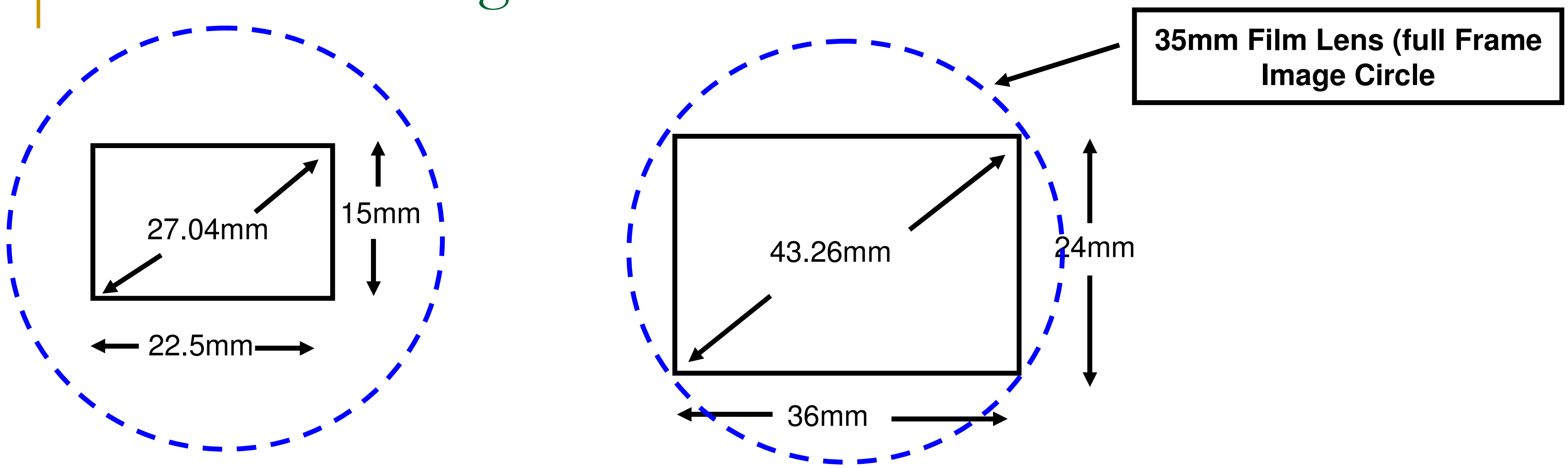


Veiling glare results from residual reflections at the lens surfaces, the lens barrel and the iris. An important part comes from the reflection at the matrix sensor which is around 40% and is directed by multiple reflections again back to the image sensor. A good lens has a veiling glare of less than 3%.
Veiling glare reduces the dynamic range of the image !

Optics 101

Sensor Sizes & Lens Conversion factors

Lens Focal Length Conversion



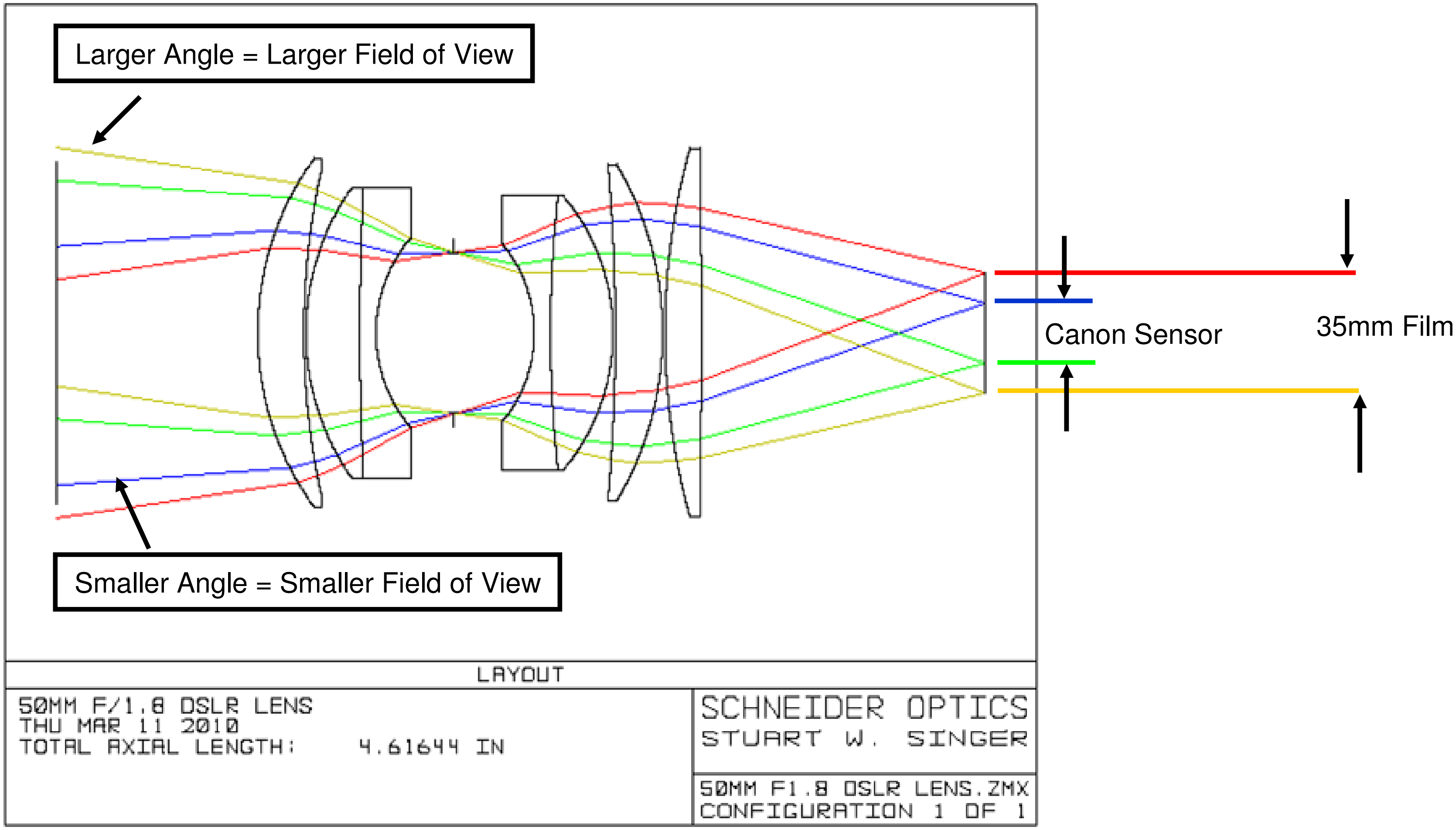
Canon Sensor (ie, 20D)

35mm Film

Cropping Factor = Focal length Multiplier = a simple ratio of the two sensor sizes

Example for Canon: 35mm Film Dimension / Sensor Dimension = (43.26 ÷ 27.04) = 1.6x Factor

Double Gauss 50mm f/1.8 (Typical SLR/DSLR Lens)



Lens Conversion Chart

The effective focal length is determined by multiplying the actual focal length of a lens by a camera's crop factor, also know as Focal Length Multiplier and Field of View Crop Factor. Before buying a lens, it's important to know the crop factor of your DSLR.

DSLR Crop factor / Focal length multiplier conversion chart

Lens	1.3X FLM	1.5X FLM	1.6X FLM	2.0X FLM
8mm	10.4mm	12mm	12.8mm	16mm
10mm	13mm	15mm	16mm	20mm
14mm	18.2mm	21mm	22.4mm	28mm
17mm	22.1mm	25.5mm	27.2mm	34mm
20mm	26mm	30mm	32mm	40mm
28mm	36.4mm	42mm	44.8mm	56mm
35mm	45.5mm	52.5mm	56mm	70mm
50mm	65mm	75mm	80mm	100mm
85mm	110.5mm	127.5mm	136mm	170mm
105mm	136.5mm	157.5mm	168mm	210mm
135mm	175.5mm	202.5mm	216mm	270mm
200mm	260mm	300mm	320mm	400mm
400mm	520mm	600mm	640mm	800mm
500mm	650mm	750mm	800mm	100mm
600mm	780mm	900mm	960mm	1200mm

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Lens Conversion Cont..

Example: **Canon 50D (Focal Length Multiplier Value (from Camera Data Sheet) = 1.6x**

You Purchased a lens with a 50mm Focal Length

To find the Effective Focal Length of the 50mm lens on the Canon Camera:

Effective Focal Length = (Lens Focal Length) x (Focal Length Multiplier)

Effective Focal Length = (50mm) x (1.6) = 80mm

Same Method to find Effective Focal Length for Zoom Lenses

Zoom Lens = 18mm – 200mm

Effective Focal Lengths = 29mm - 320mm

Topics for a Possible 2nd Presentation

- Lens Performance (MTF)
- CCDs / CMOS Sensors
- Pixels
- Pastic Elements /
- Aspherics Elements?
- ????????

Contact Information

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