Vision Systems Design
Webinar
9 September 2015

How to Choose a Machine Vision Camera for Your Application.

Andrew Bodkin
Bodkin Design & Engineering, LLC
Newton, MA 02464
617-795-1968
wab@bodkindesign.com
www.bodkindesign.com

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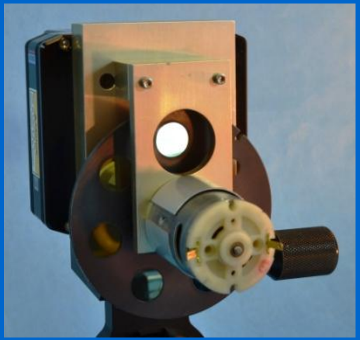

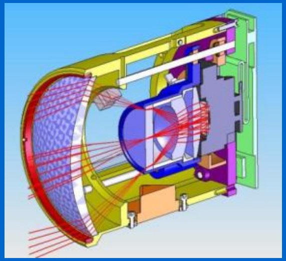

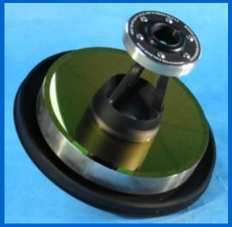

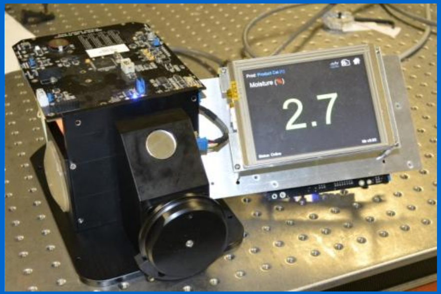

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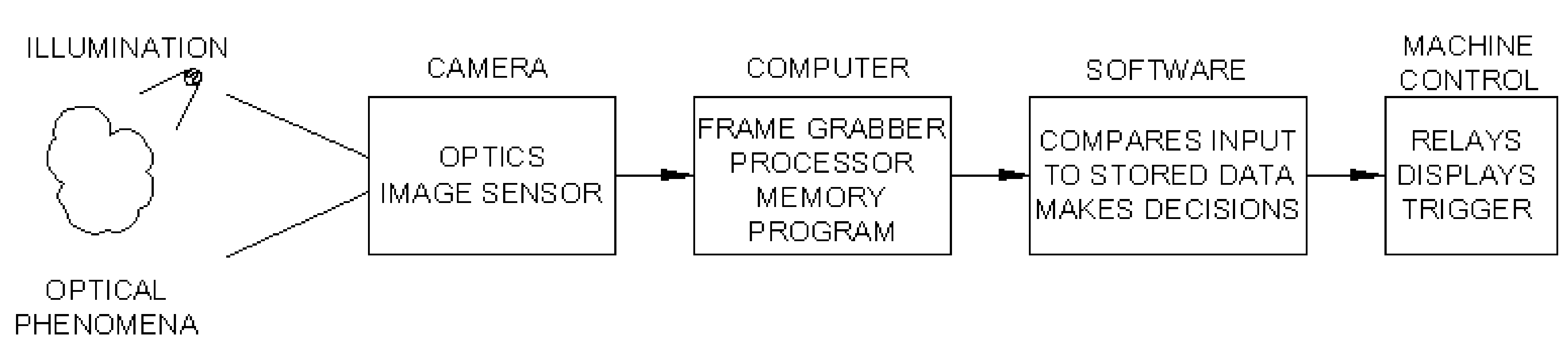
Machine Vision



Measure optical phenomena

- spatial location (size)
- reflectivity/absorption
  - color-imaging / spectroscopy
- stop motion / time studies
- phase (transparent imaging)
- self emission (temperature)
- polarization (stress)

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Front End

- Common to all these systems are cameras
  - lenses
    - focal length, f/number, spatial resolution, depth of focus, telecentricity, uniformity
  - focal plane array
    - pitch, pixel count, color filter, read out sequence, bit depth, well depth, integration time, dynamic range
- This webinar will explain how to select the components for the camera to match your application

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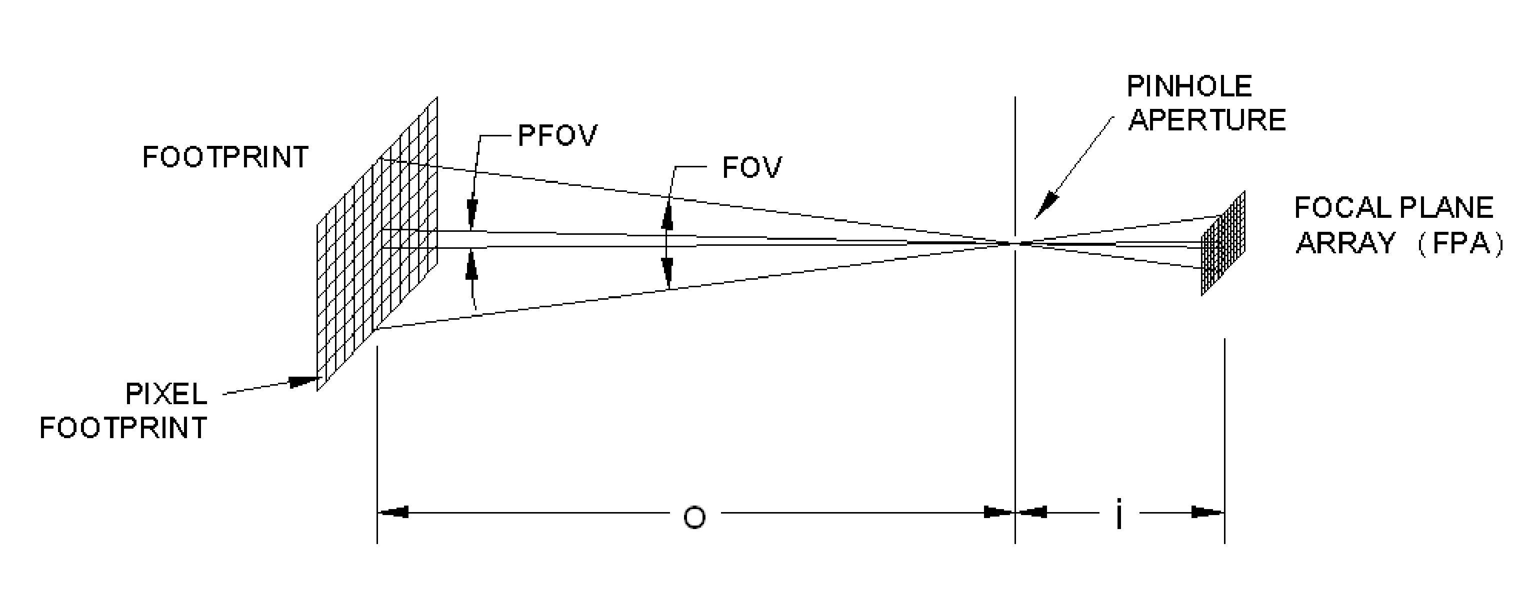
Pinhole Imager

The fundamental process of imaging



- A ray of light passes through a pinhole and makes a spot
- The sum of the spots is an image
- All other systems are simply improvements on this fundamental imager

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Definitions

- Magnification=i/o,
- Pixel field-of-view PFOV (radians)

$$PFOV = \frac{p}{i} = \frac{p}{f}$$

p=pixel pitch

- Field-of-view FOV (radians)

$$FOV = PFOV \cdot (\#\, pixels)$$

horizontal and vertical

- Footprint (mm)

$$Footprint = FPA\, dim \cdot mag = FOV \cdot o$$

- Pixel footprint (mm)

$$= p \cdot mag = PFOV \cdot o$$

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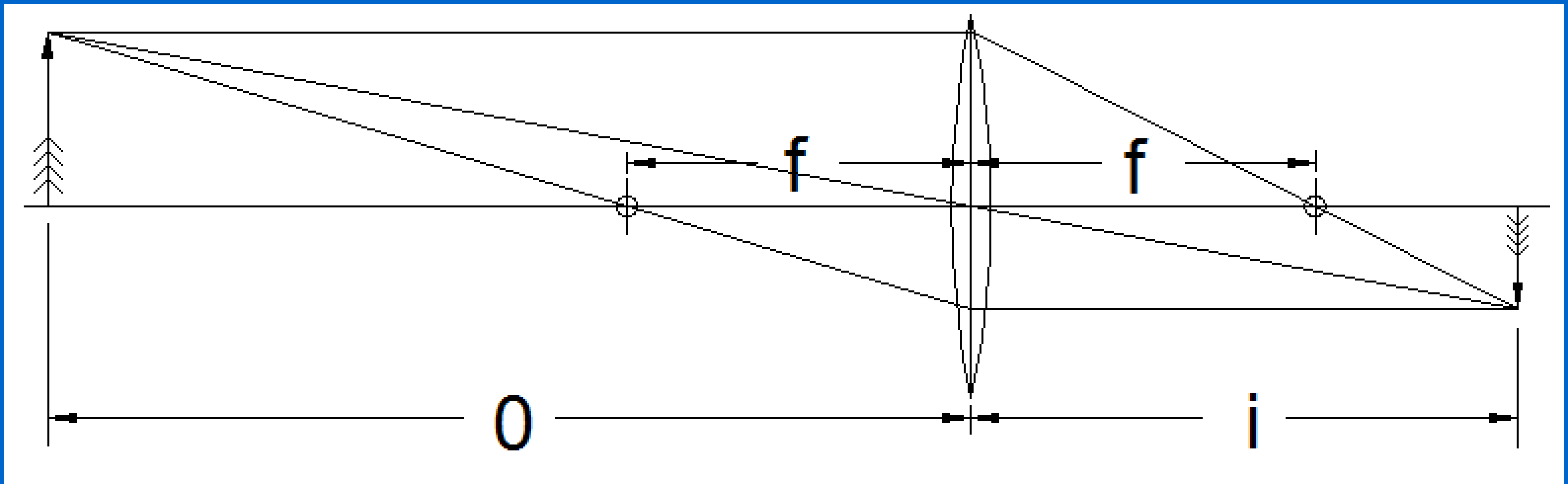
Layout of a Thin Lens



1. Light travels left to right
2. Rays leave the object and pass through the lens
3. Rays parallel to the optic axis pass through the back focal point
4. Rays go straight through the center of the lens
5. Rays through the front focal point exit parallel to the optic axis

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First Order Optical Parameters

- Thin lens formula

f=focal length

o=object distance

i= image distance

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$

How to focus the image

- Magnification

$$Mag = \frac{i}{o}$$

How big is the image

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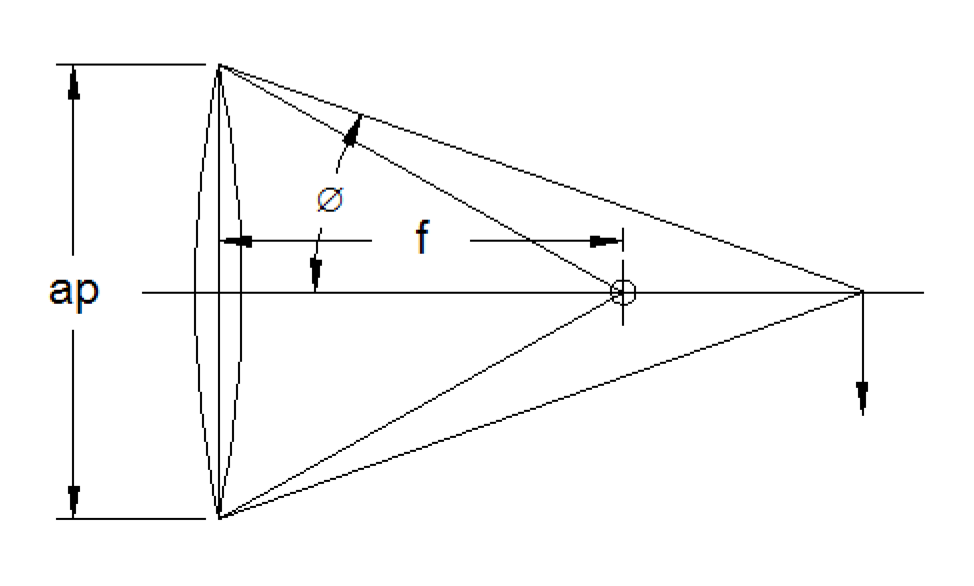
Image Intensity

- F-number / Numerical Aperture

  f/=f-number
  NA=Numerical Aperture
  ap=aperture diameter
  ø=edge ray angle at the image

$$f/= \frac{1}{2NA} = \frac{1}{2\sin(\text{ø})}$$

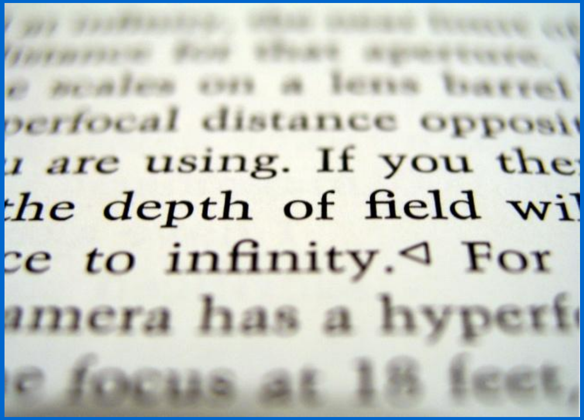
$$f/\cong \frac{f}{ap}$$

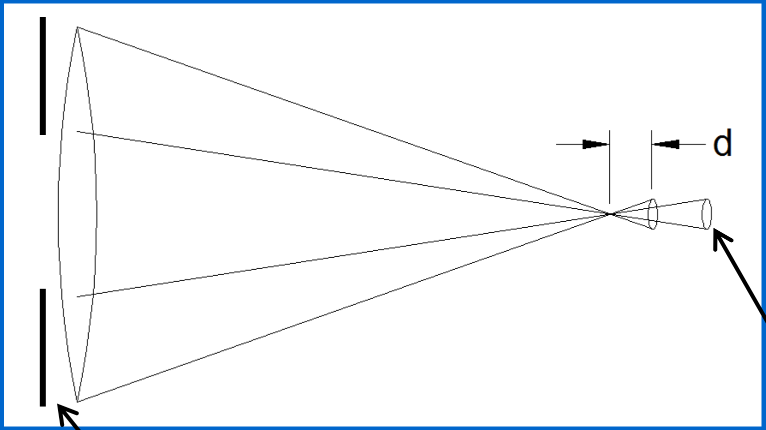


Depth of Field

Image blur spot diameter increases with defocus

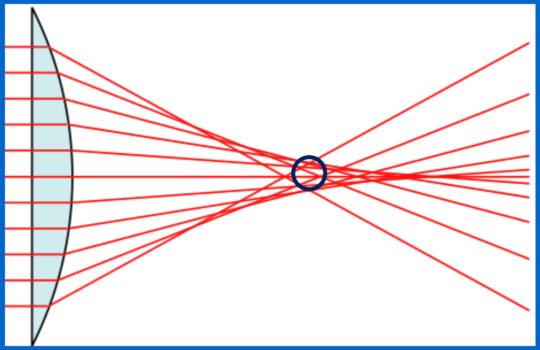
Is a continuum and is increased by reducing the f-cone





Blur spot

Aperture stop



Blur spot diameter from optical aberrations and diffraction

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Focal Plane Array

- 2D and linear arrays
- Color or Monochrome, Bayer filter
- Pixel pitch
- Format
- Pixel count, total count, horizontal x vertical
- Frame rate
- Bit depth
- Progressive Scan (rolling shutter)/framing (global shutter)

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Format

- Aspect Ratio 4:3, 16:9
- 1” sensor has 16 mm diagonal (1” OD vidicon tube)

Sensor Format	Diagonal (mm)	Width (mm)	Height (mm)	Representative Sensor
1/3"	6	4.8	3.6	Micron MT9M131
1/2"	8	6.4	4.8	Kodak KAF0400
1/1.8"	8.93	7.18	5.32	Sony ICX452
2/3"	11	8.8	6.6	Sony ICX285
1"	16	12.8	9.6	Kodak KAI2000
4/3"	21.6	17.3	13	Kodak KAI4000

Arcane units. Simply multiply pitch by pixel count H x V

Diagonal is used to select lens

$$Diag = \sqrt{H^2 + V^2}$$

Pixel Pitch

- Common pixel pitch
  - 7.4, 5.5, 5.6, 6.5, 4.7, 3.27, 2.2, 1.6, 1.25 um
  - Small pixels <2.5um are sub blur spot, do not increase resolution

b=blur radius
λ=wavelength

$$b = 1.22 \cdot \lambda \cdot f/$$

1.22*.5um*4=2.44um

- Pixel limited resolution

R=resolution (lp/mm)
p=pixel pitch (mm)

$$R = \frac{1}{2 \cdot p}$$

- Rated in H x V
  - 1280 x 1024=1.3 MP

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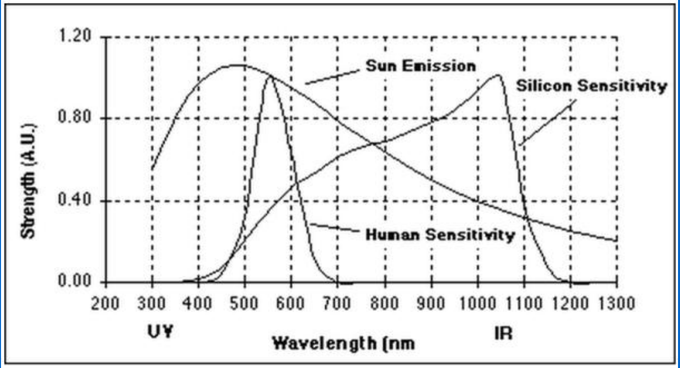
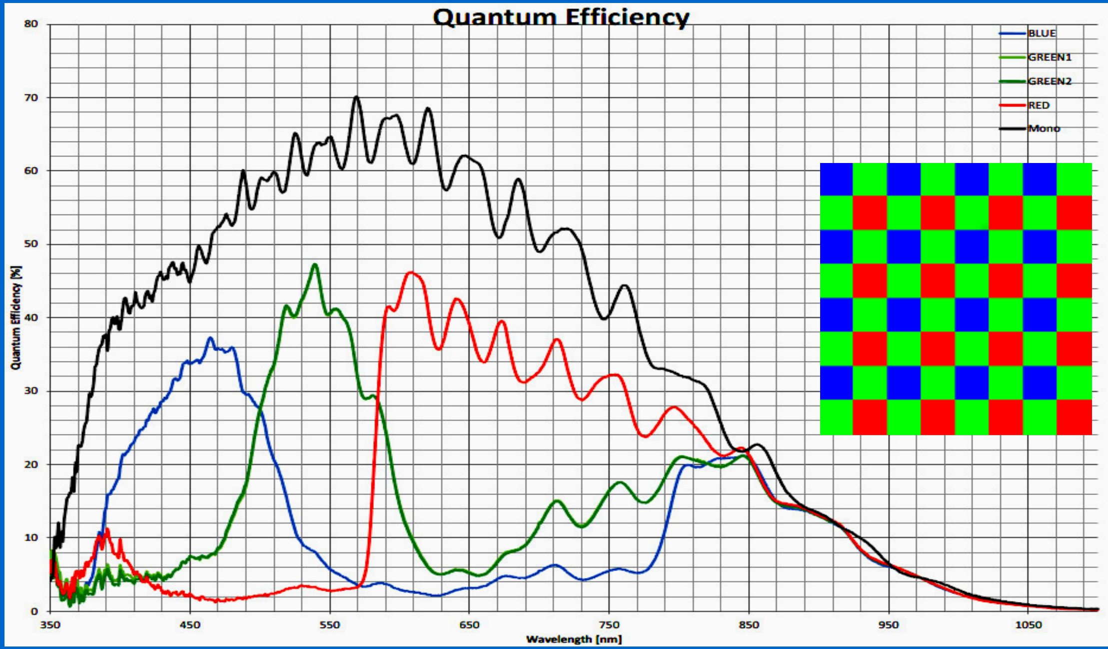
Bayer Filter

- Monochrome FPA, resolution is 2x pixel pitch
- Color FPA, Bayer filter reduces resolution by half, 4X pixel pitch



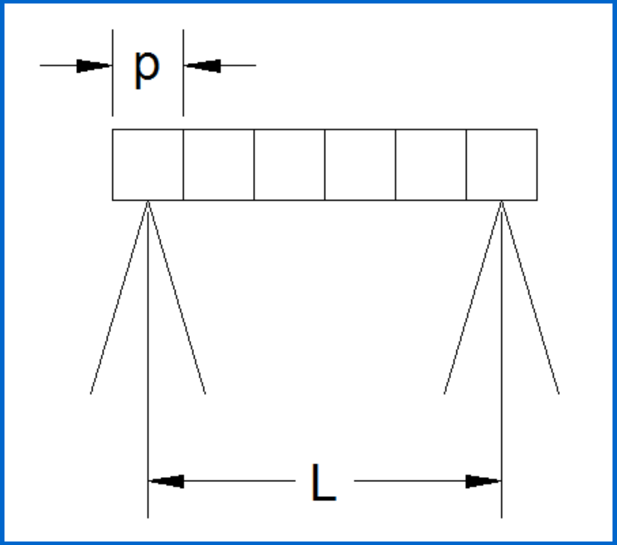
Eye spectral sensitivity
Native silicon sensitivity
Solar illumination



FPA spectral sensitivity

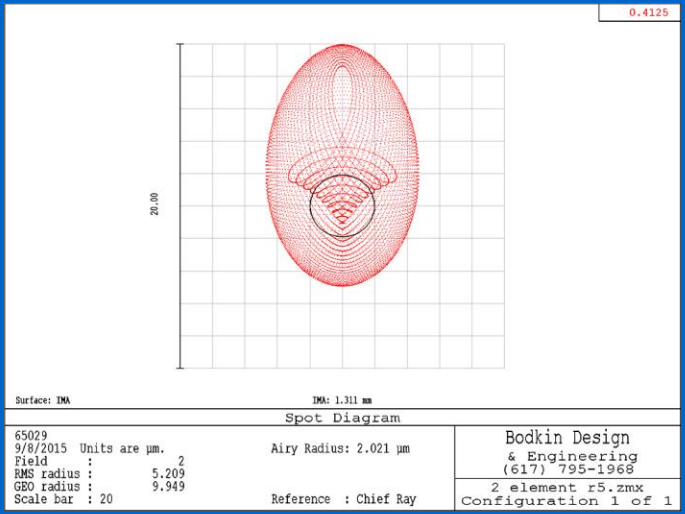
Accuracy

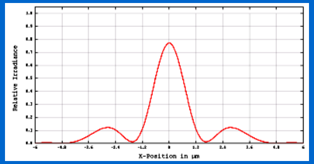
Pixel Limited Resolution



Distance = L ± p

Optics Limited Resolution



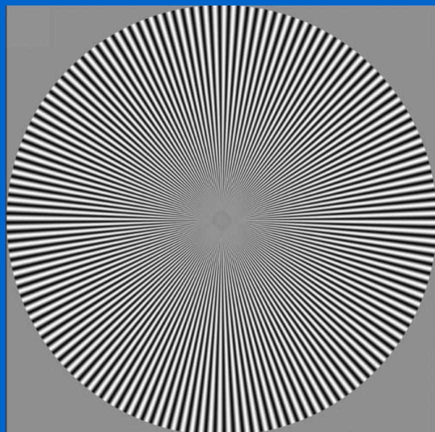


Distance = L ± b

$$b = 1.22 \cdot \lambda \cdot f/$$

Diffraction limited blur spot

Optics Resolution



Radial spokes

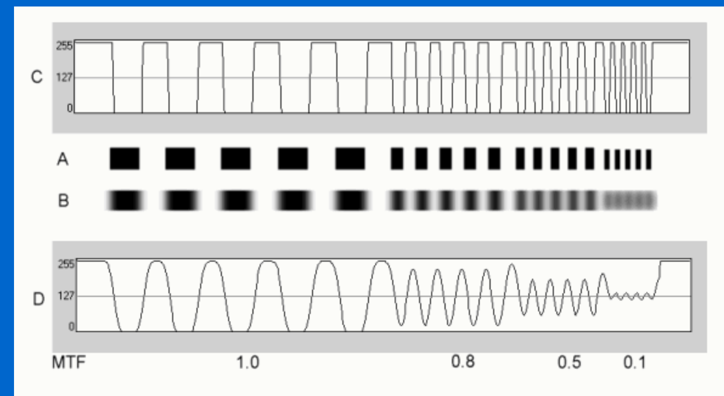
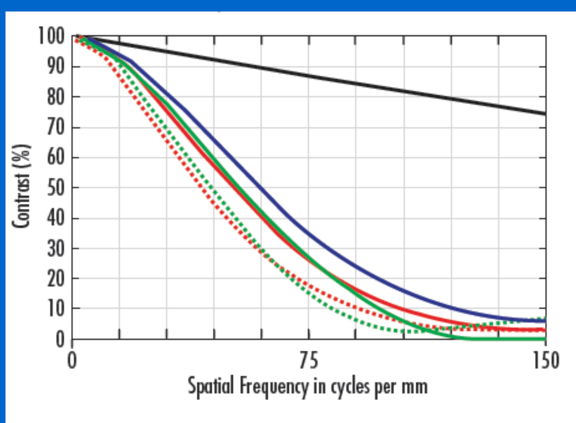
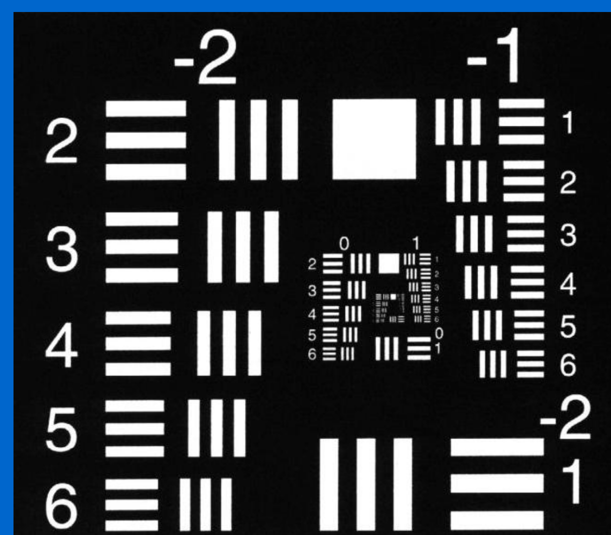
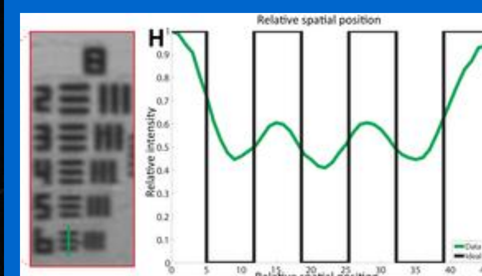


Image line scan



MTF curve





USAF 1951 Test Chart

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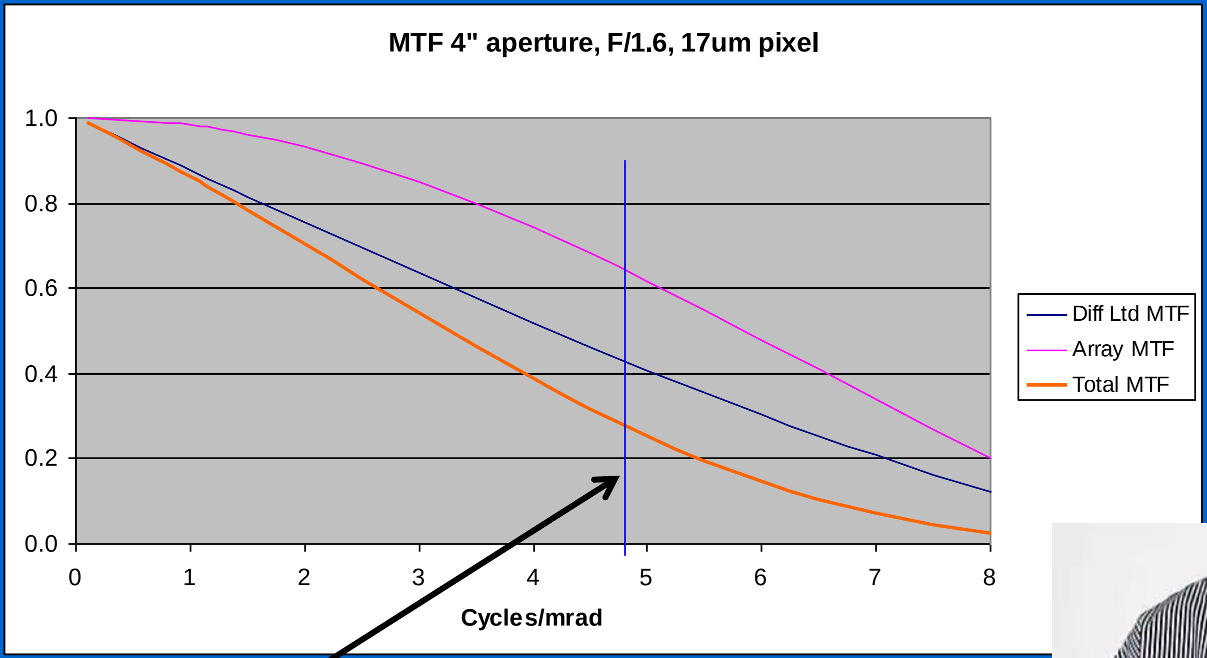
System MTF



Nyquist cut-off

$$R = \frac{1}{2 \cdot p}$$

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Lens Specification

- Mounting flange/flange focal distance
  - C-mount /17.526 mm
  - CS-mount /12.5 mm
  - SLR lenses proprietary
    - F-mount, Canon, etc. ~ 46.5mm
- Fixed focus/varifocal/zoom
- Field diagonal

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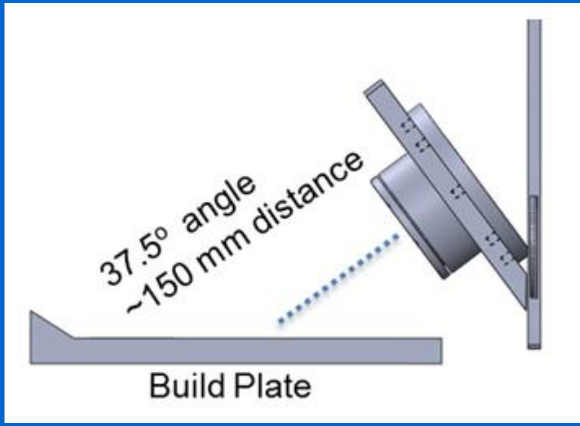
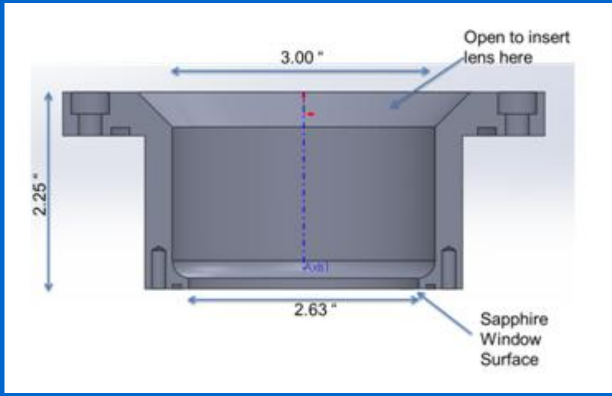
Example





- Maximize magnification
- Lens outer diameter <75mm
- Working distance >150mm
- Fill f/4 cold stop

Object distance: 200 mm						
Magnification	Fl (mm)	Aperture (mm)	f/	Image distance (mm)	Pixel footprint	Hor. field size
0.75	85.7	37.8	2.27	150	0.139	12.8
1	100	50.4	1.98	200	0.104	9.6
2	133.3	100.8	1.32	400	0.052	4.8
3	150.0	151.2	0.99	600	0.035	3.2

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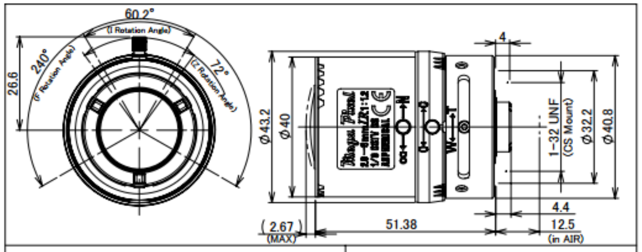
Lens Selection

Mega-Pixel Mega-Pixel lenses are suitable for sensors with a resolution of 720p or more

Imager Size [?]	Mount [?]	Image	Focal Length [?]	F No. [?]	Description	Model # [?]	Iris [?]	Specs
1/1.8"	C-Mount		4-13mm	F/1.5	5 Mega-Pixel Near IR Corrected Lens (1/1.8" 4-13mm F/1.5)	M118VG413IR	DC Auto	
						M118VM413IR	Manual	
						M118VP413IR	Stepper Motor	
1/2.7"	CS-Mount		2.8-8mm	F/1.2	DOUBLE VARI-FOCAL The Simple Choice Double Vari-Focal Series 3 Mega-Pixel IR-corrected Lens (1/2.7" 2.8-8mm F/1.2) (1/2.7" 8-50mm F/1.6) IR	M13VG288IR	DC Auto	
						M13VM288IR	Manual	
						M13VP288IR	Stepper Motor	
			8-50mm	F/1.6		M13VG850IR	DC Auto	
						M13VP850IR	Stepper Motor	
1/2.7"	CS-Mount		2.8-12mm	F/1.4	3 Mega-Pixel IR-corrected lens (1/2.7" 2.8-12mm F/1.4)	M13VG2812IR	DC Auto	

M13VM288IR Mega Pixel



Imager Size	イメージャーサイズ		1/3
Mount Type	マウント		CS
Focal Length	焦点距離		2.8 ～ 8 mm
Aperture Range	絞り範囲		F/1.2 ～ Close
Angle of View(Horizontal×Vertical) 画角（水平×垂直）	1/3	Wide	100.1° × 72.9°
		Tele	35.8° × 26.8°
	1/4	Wide	72.9° × 53.9°
		Tele	26.8° × 20.1°
Focusing Range	フォーカス範囲		0.3m ～ ∞
Operation 操作方法	Focus フォーカス		Manual w/lock 手動ロック付
	Zoom ズーム		Manual w/lock 手動ロック付
	Iris アイリス		Manual w/lock 手動ロック付
Filter Size	フィルターネジ径		―――
Back Focus(in air)	バックフォーカス(in air)		Wide : 8.339 ～ 14.944mm
Wave Length	対応波長		Visible Light ～ Near Infrared 可視光域 ～ 近赤外域
Operating Voltage	作動電圧		―――
Weight	重量		61 g ± 4 g
Operating Temperature	動作温度範囲		−20℃ ～ +60℃
Wiring Diagram	配線図		

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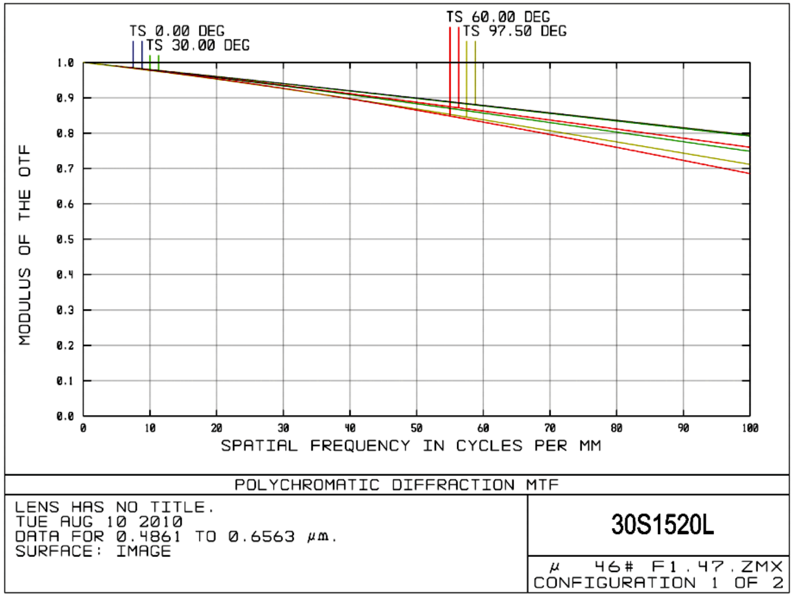
Tamron varifocal lenses

Fixed Focus Lenses

CS Mount

Model No.	MTF	Focal Length	Aperture	Back Focal Length	Sensor	Field of View			M.O.D.	Dimensions		Iris	Focus	Weight
		(mm)	(F-Stop)			D	H	V	m	D	L			g
30S1520L	MTF	1.5	2.0	4.57	1/3"	195	195	195	0.1	30	16.0	Fixed	Manual	31.0
30SK0220L	MTF	2.0	2.0	5.6	2/3"	195	195	195	0.08	30	18.5	Fixed	Manual	18.0
30M028020F	N/A	2.8	2.0	6.38	1/3"	125	100	74	0.2	30	11.5	Fixed	Manual	25.0
30SH0416L	MTF	4.0	1.6	7.21	1/2"	146	96	68	0.2	30	11.1	Fixed	Manual	55.0
30SH0616L	MTF	6.0	1.6	8.73	1/2"	88	65	46	0.2	30	15.9	Fixed	Manual	29.4
30S0618N-IR	MTF	6.0	1.8	8.75	1/3"	60	48	34.5	0.2	30	14.			
30S0818L	MTF	8.0	1.8	5.4	1/3"	45	35.5	26	0.2	30	14.			
30SH0816L	MTF	8.0	1.6	5.4	1/2"	62	48	35	0.2	30	14.			
30SJ0818LD	MTF	8.0	1.8	9.55	1/1.8"	62	51	39.5	0.2	30	18.			
30SH1216L	MTF	12.0	1.6	6.54	1/2"	38.6	31	23	0.2	30	14.			



Videology

Megapixel Lenses

Feature Indications

FIXED — **Fixed Focal**: High performance single focal lens for the best image quality

5 Mega — **For Megapixel Camera**: For 5 Megapixel Camera

MANUAL — **Manual Iris**: Manually-operated iris

C-mt — **C Mount**: Screw-in mounting commonly used in FA lenses

F1.4 — **Wide Aperture Rate**: Lens with the wide aperture rate, optimizing the sensitivity of cameras

METAL — **Metal Mount**: Metal mounting with high accuracy and durability

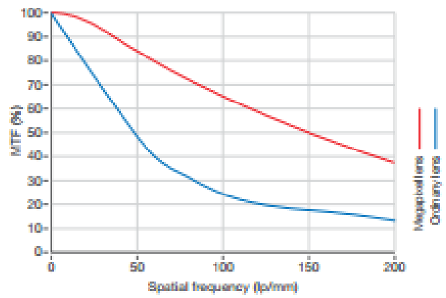
··· With locking knob for iris and foucs

··· Using an extension tube longer than 5mm the M.O.D. will increase to 0.3m

··· Using an extension tube longer than 5mm the M.O.D. will increase to 0.5m

Megapixel Supporting Lens

We have realized a high resolution, compact, and lightweight lens supporting to megapixel by thoroughly reducing aberrations based on design technology cultivated from broadcast TV lenses. The chart shown at the right compares megapixel supporting lens and the MTF of an ordinary CCTV lens. As the number of TV lines increases, the disparity in MTF becomes bigger.



		HF12.5SA-1	HF16SA-1	HF25SA-1	HF35SA-1	HF50SA-1	HF75SA-1
Focal Length (mm)		12.5	16	25	35	50	75
Iris Range		F1.4~F22	F1.4~F22	F1.4~F22	F1.4~F22	F1.8~F22	F1.8~F22
Operation	Focus	Manual	Manual	Manual	Manual	Manual	Manual
	Iris	Manual	Manual	Manual	Manual	Manual	Manual
Angle Of View (H×V)	2/3"	38°47' x 29°35'	30°45' x 23°18'	19°58' x 15°02'	14°20' x 10°46'	10°03' x 7°33'	6°43' x 5°02'
	1/2"	28°43' x 21°44'	22°37' x 17°04'	14°35' x 10°58'	10°27' x 7°51'	7°19' x 5°30'	4°53' x 3°40'
	1/3"	21°44' x 16°23'	17°04' x 12°50'	10°58' x 8°14'	7°51' x 5°53'	5°30' x 4°07'	3°40' x 2°45'
Focusing Range (From Front Of The Lens) (m)		∞ ~ 0.1	∞ ~ 0.1	∞ ~ 0.1	∞ ~ 0.2	∞ ~ 0.4	∞ ~ 0.9
Object Dimensions at M.O.D. (H×V) (mm)	2/3"	83 x 62	69 x 51	44 x 33	50 x 38	70 x 52	101 x 76
	1/2"	60 x 45	50 x 37	32 x 24	37 x 27	51 x 38	74 x 55
	1/3"	45 x 34	37 x 28	24 x 18	27 x 21	38 x 28	55 x 41
Back Focal Distance (in air) (mm)		16.07	17.99	22.32	14.99	17.81	24.43
Exit Pupil Position (From Image Plane) (mm)		-101	-172	-140	-37	-49	-52
Filter Thread (mm)		M49 x 0.75	M49 x 0.75	M49 x 0.75	M49 x 0.75	M49 x 0.75	M49 x 0.75
Mount		C	C	C	C	C	C
Mass (g)		295	285	315	185	240	305
Remarks		With Metal Mount	With Metal Mount	With Metal Mount	With Metal Mount	With Metal Mount	With Metal Mount

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Fujinon

FPA selector

Select	Product	Data Sheet	Description	Type	Megapixels	Frame Rate (fps)	Optical Format	Shutter Type	Pixel Size (µm)	Color
								Global Shutter		RGB
	AR0136AT		1.2 MP 1/3" CMOS Image Sensor	CMOS	1.2	45	1/3 inch	Electronic Rolling	3.75 x 3.75	RGB
	AR0140AT		1.0 MP 1/4" CMOS Image Sensor	CMOS	1	60	1/4 inch	Electronic Rolling	3.0 x 3.0	RGB
	AR0140CS		1.0 MP 1/4" CMOS Image Sensor	CMOS	1	60	1/4 inch	Electronic Rolling	3.0 x 3.0	RGB
	AR0141CS		1.0 MP 1/4" CMOS Image Sensor	CMOS	1	60	1/4 inch	Electronic Rolling	3.0 x 3.0	Mono RGB
	AR0230AT		2 MP 1/3" CMOS Image Sensor	CMOS	2.1	30	1/2.7 inch	Electronic Rolling and Global Reset Release	3.0 x 3.0	Mono RGB
	AR0230CS		2 MP 1/3" CMOS Image Sensor	CMOS	2.1	60	1/2.7 inch	Electronic Rolling and Global Reset Release	3.0 x 3.0	RGB
	AR0261		2 MP 1/6" CMOS Image Sensor	CMOS	2.1	60	1/6 inch	Electronic Rolling	1.4 x 1.4	RGB
	AR0330		3 MP 1/3" CMOS Image Sensor	CMOS	3.5	60	1/3 inch	Electronic Rolling	2.2 x 2.2	RGB
	AR0331		3 MP 1/3" CMOS Image Sensor	CMOS	3.1	60	1/3 inch	Electronic Rolling	2.2 x 2.2	RGB
	AR0542		5 MP 1/4" CMOS Image Sensor	CMOS	5	15	1/4 Inch	Electronic Rolling	1.4 x 1.4	RGB
	AR0543		5 MP 1/4" CMOS Image Sensor	CMOS	5	15	1/4 inch	Electronic Rolling	1.4 x 1.4	RGB
	AR0833		8 MP 1/3" CMOS Image Sensor	CMOS	8	30	1/3.2 inch	Electronic Rolling	1.4 x 1.4	RGB
	AR0835		8 MP 1/3" CMOS Image Sensor	CMOS	8	42	1/3.2 inch	Electronic Rolling	1.4 x 1.4	RGB
	AR1011		10 MP 1" CMOS Image Sensor	CMOS	10.8	60	1 inch	Electronic Rolling	3.4 x 3.4	RGB
	AR1335		13 MP 1/3" CMOS Image Sensor	CMOS	13	30	1/3.2 inch	Electronic Rolling	1.1 x 1.1	RGB
	ARX342CS		VGA 1/4" CMOS Image Sensor	CMOS	VGA	60	1/4 inch	Electronic Rolling	5.6 x 5.6	RGB

ON-semiconductor

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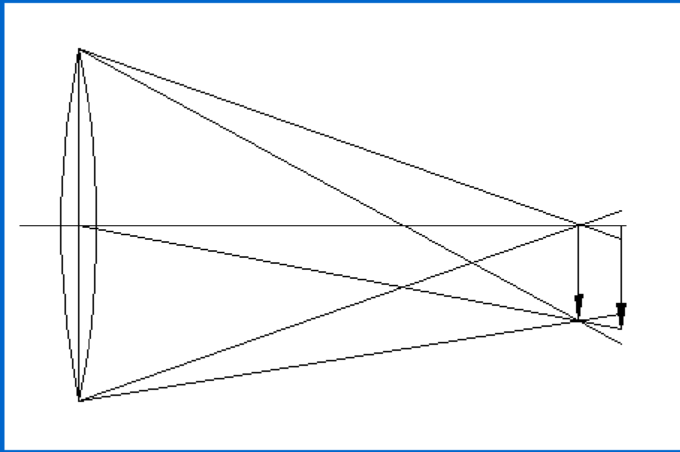
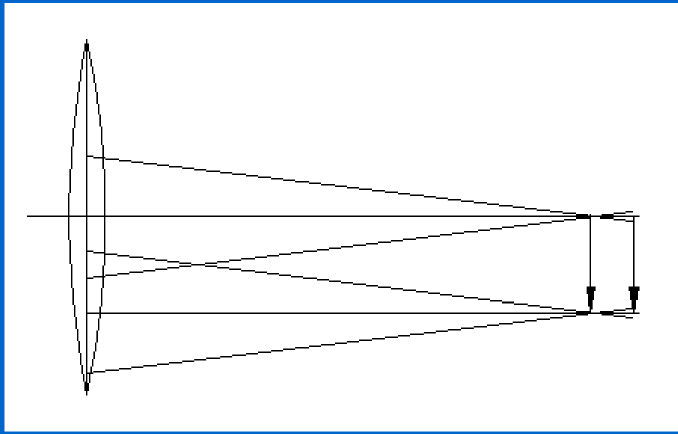
Telecentric Lens

Defect of focus can cause magnification changes. Not good for metrology. Objects in front of target look bigger than they are.



Conventional

Telecentric system all the cones are parallel. (chief rays are parallel to the optic axis). no magnification change with defocus.



Telecentric

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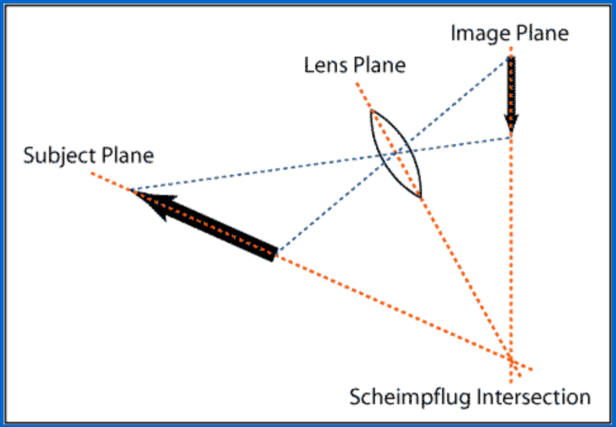
Scheimpflug Imaging

Conventional lens the object plane is perpendicular to the camera lens. Problematic for off-axis imaging



Lens tilted to the Scheimpflug condition, the image plane lays down. Useful for all object s to be in focus

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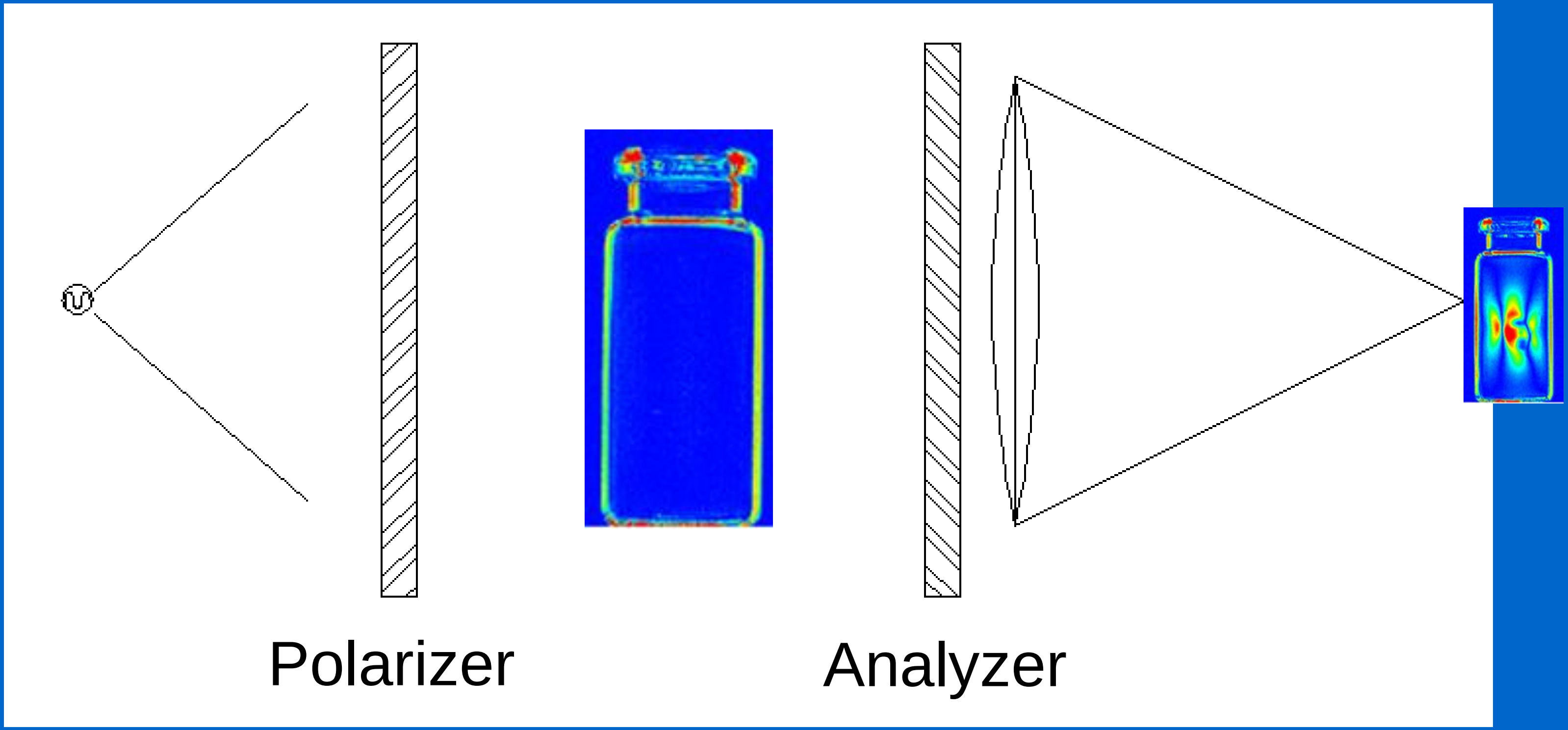
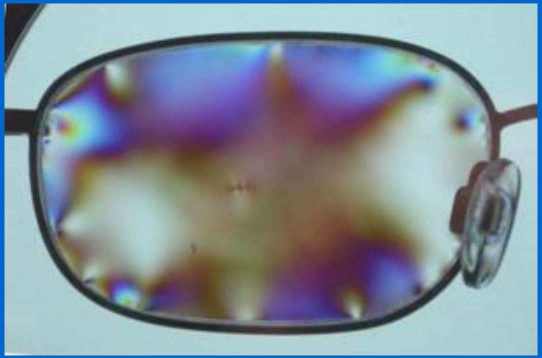
Polarization Imaging



Visualize stress birefringence in transparent materials



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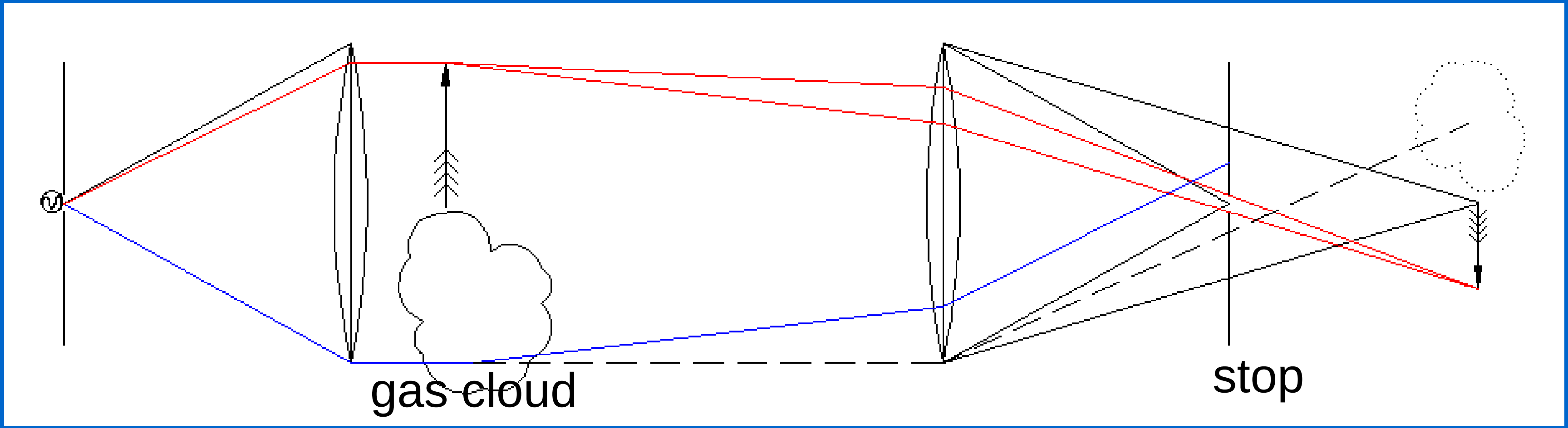
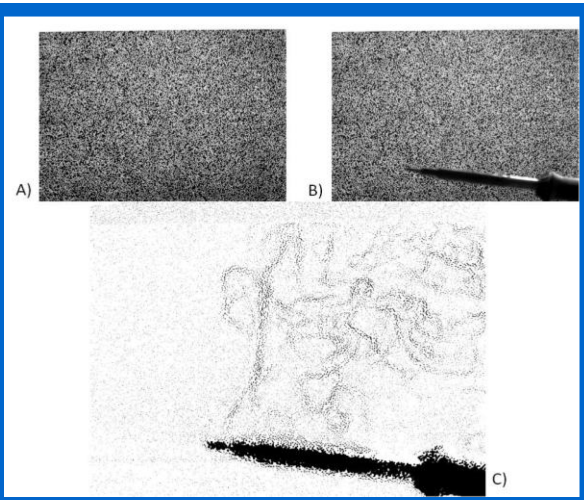
Schlieren Photography

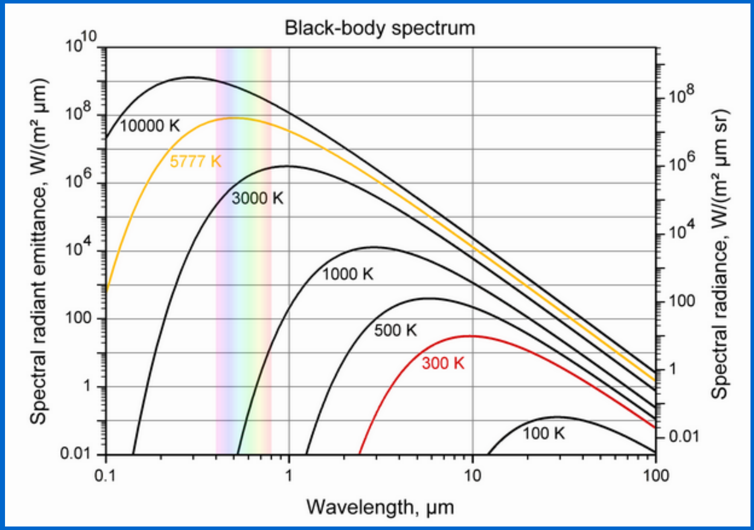
Useful for imaging gas flows, glass striations, transparent objects



Background-Oriented Schlieren

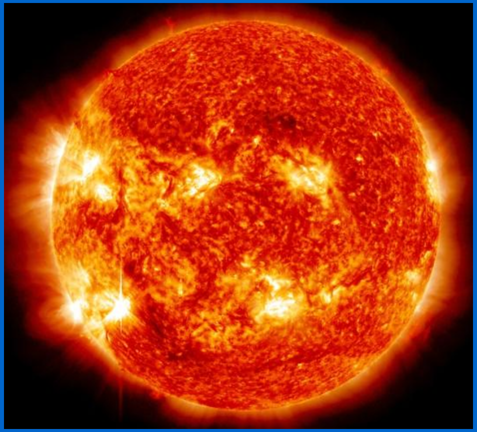


Thermal Imaging



incandescent bulb
2700K

campfire
1100K



sun
5777K

human
310K

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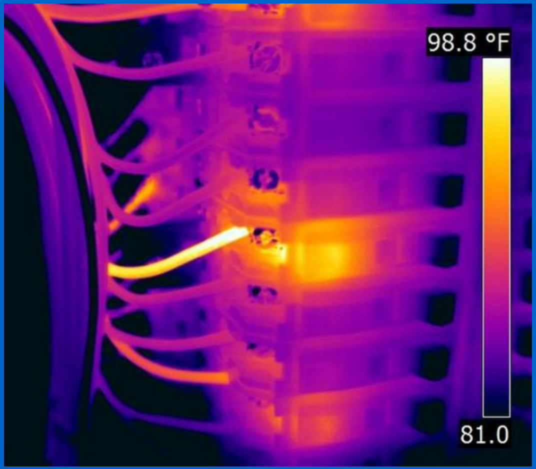
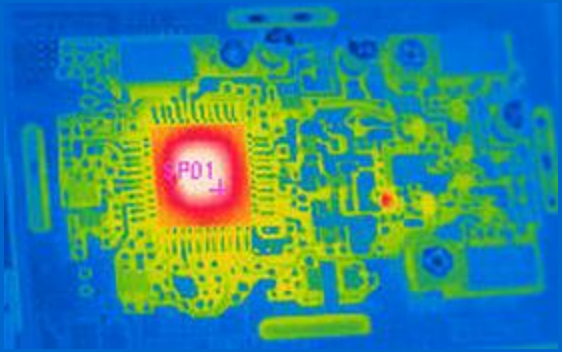
Thermal Imaging Applications

Thermal imaging is low cost and common

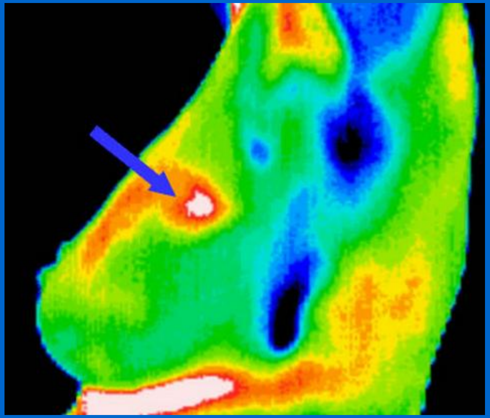


Bad contacts get hot
Relative temperature, emissivity unknown



Electronic inspection

Insulation problem



Tumors are hot

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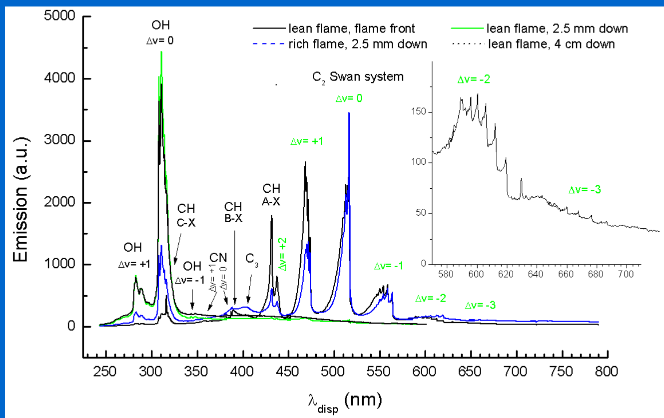
Spectral Imaging

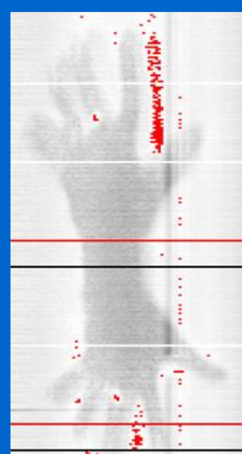


Spectral emission of a flame

More than RGB

Precision measurement of spectral reflectance or absorbance (or self emission)

- Determine chemical composition
  - QC of colors
    - make-up
    - paints/pigments
  - moisture content
  - coating density and distribution
  - combustion mix ratio
  - determine emissivity
  - crop stress
  - melanoma



Line scan spectral imaging camera measures moisture

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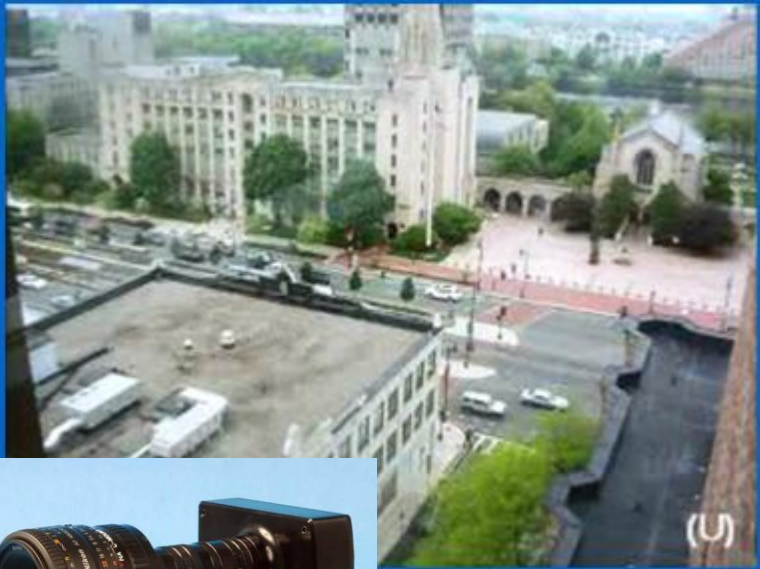
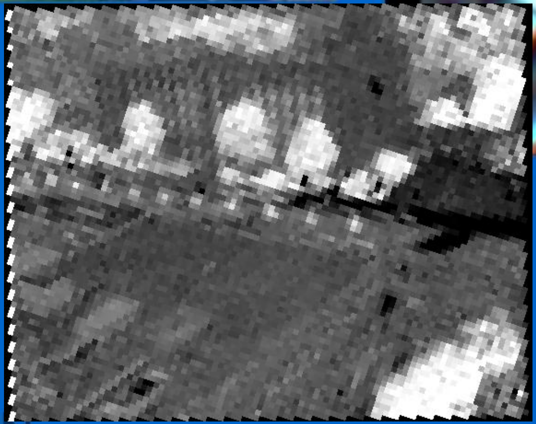
Spectral Imaging

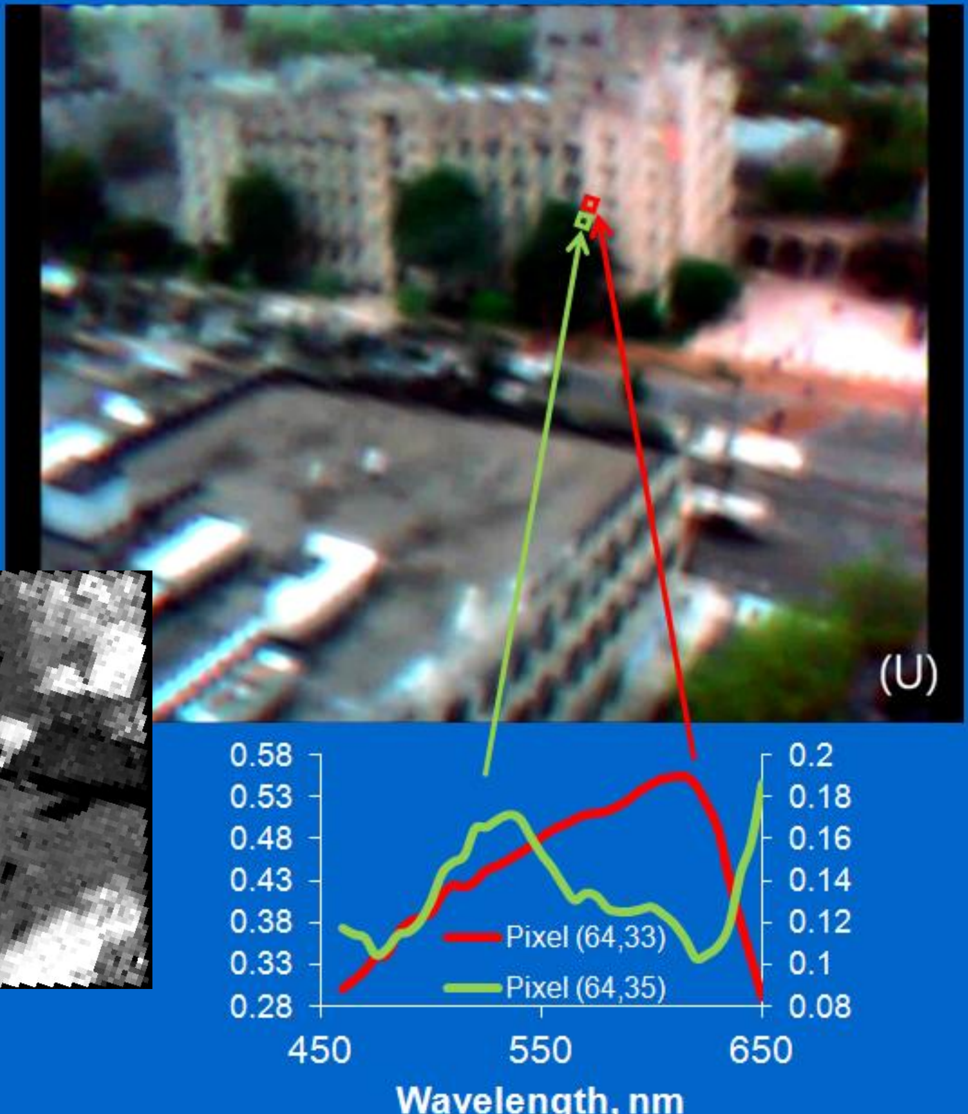
Color video camera



Chlorophyll/
camouflage detection



VNIR-40 HPA camera



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Questions

Andrew Bodkin
Bodkin Design & Engineering, LLC
Newton, MA 02464
617-795-1968
wab@bodkindesign.com
www.bodkindesign.com

Andrew Bodkin has been a camera designer for the last 27 years. Designing camera systems for the military, biological, industrial and commercial users. He has built image intensified cameras, high speed cameras, polarization sensitive cameras, spectral analysis cameras, infrared cameras, moisture cameras, airborne cameras and worked on cameras for missile guidance and reconessence. He has worked for Textron, Loral, Ion Optics, and for the last 15 years has run his own engineering services business, building and designing cameras. He has over 7 patents for the equipment he has invented. The company now produces a proprietary design of high speed hyperspectral cameras that are used for chemical analysis for biological detection and quality control, as well as precision thermal analysis.

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