2k,4k,8k and the Bermuda triangle of depth-of-field, f/number and sharpness

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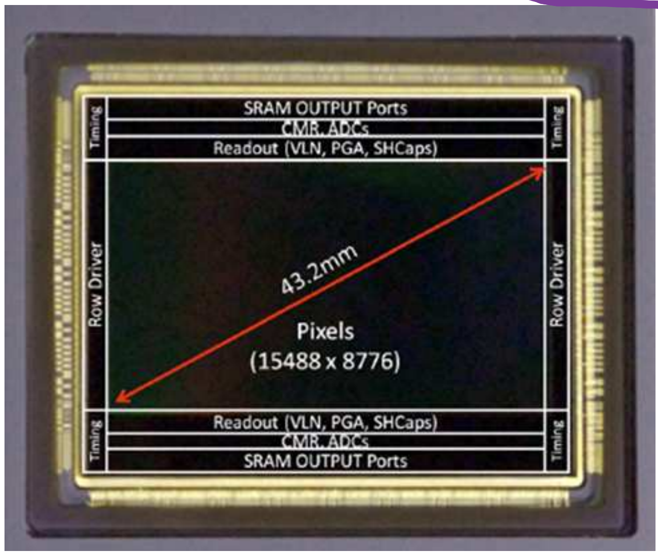
Agenda

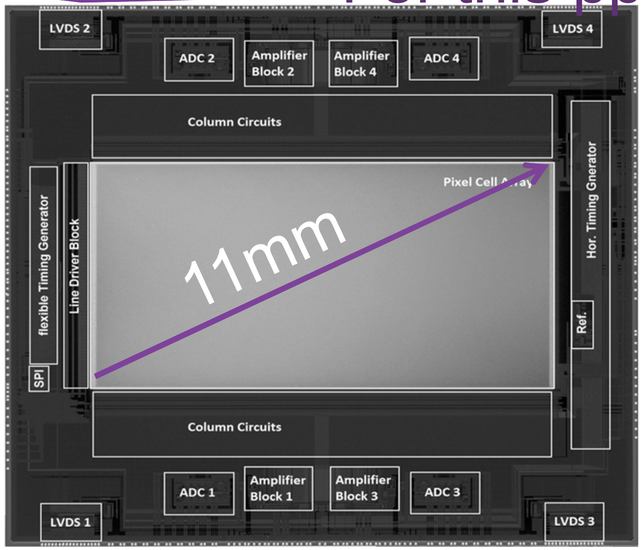
- Sensitivity
- Sharpness
- Depth-of-field
- Summary
  - The good news
  - The bad news for sports and the good news for drama
  - What can one do for sports

Everything between 11 mm and 44 mm

- And pixelcount between 2 Mpixels - 133 Mpixels
- And pixelwidth between 1.1 um - 5.0 um
- And between f/1.4 - f/11, 2000 lux, 89.9%, 3200K

Reference
For this ppt





Sensitivity's☺

- 1920 or 2048, 3840 or 4096, 7680 or 8192
  - For an engineer just 6.7%
  - But the sensitivity's are at least 100%

  - Funny: 1080 stays 1080 where the raster is 1125x2200

Sensitivity

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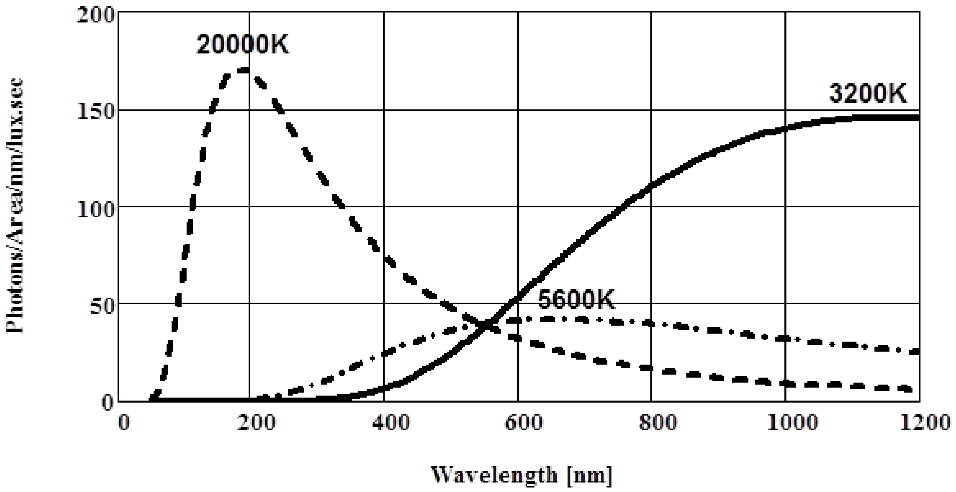
Sensitivity

- Photon flux of a blackbody radiator at 3200K, 5600K and 20000K, Area is in [µm2].

$$photonsG(T) := \frac{A_{cell} \cdot T_{int}}{h \cdot c} \cdot \frac{E_v \cdot \rho}{4 \cdot F^2} \cdot \frac{\int_{400}^{750} P(\lambda, T) \cdot \tau_{IR}(\lambda) \cdot \tau_{lens}(\lambda) \cdot \tau_{KssG}(\lambda) \cdot \lambda \, d\lambda}{\int_{400}^{750} V(\lambda) \cdot P(\lambda, T) \, d\lambda}$$



Acell: Pixel area
Tint: exposure time
Ev: scene illumination
Rho: reflection coefficient: 89.9%
F: f-number of the lens
P: blackbody radiator
IR: transmittance curve of the IR filter
KSS: transmittance of the colorsplitter
V: the eye weight curve

Sensitivity

- 2000 lux; 89.9 %; 3200K, f/11
- Blackbody radiator 3200K: 6000 photons/lux.sec/um2@BW+IR
  - A 5um pixel collects in 16.67ms this is HDTV

Mastergain	Red	Green	Blue
0dB	3206 photons	3029 photons	1114 photons

Sensitivity

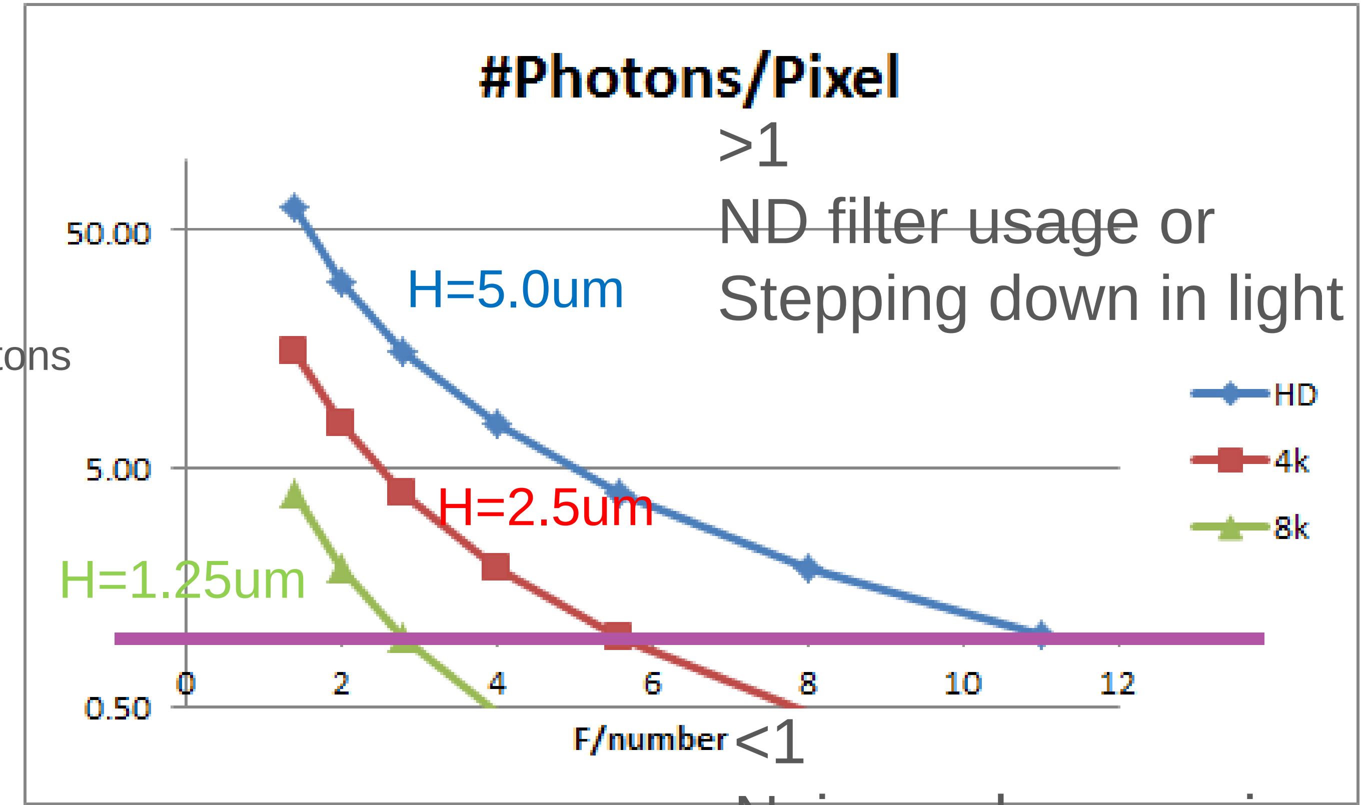
- Pixel area
  - Pixel area H*H
- #photons
  - F: f/number
  - 3000 photons in green at f/11, 2000lux, 89.9%, 3200K, 5um, 16.7ms
- Noise
  - Readnoise, noise black
  - Shotnoise, photon generated
- **Scaling**
  - **When ratio between pixel-size and f-number (H/F) is constant then the number of photons on the pixel is constant**

$$\text{Sensitivity} \;\square\; \left(\frac{\text{H}}{\text{F}}\right)^2$$

$$\text{Sensitivity} \;\square\; \left(\frac{\text{Diagonal}}{\text{F}\cdot\text{Resolution}}\right)^2$$

Sensitivity at 2/3” as function of f-number

For equal number of photons
HD f/8 (5.0um pixel)
4k f/4 (2.5um pixel)
8k f/2 (1.25um pixel)



Noise reducer region

Sharpness

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MTF at Nyquist

- An imager is a 2-dimensional spatial sampler.
- The Nyquist frequency is half the sample frequency. It is the frequency up to which one can reconstruct a sampled signal
  - The sample frequency can be expressed in lp/mm and is 1/pixel-pitch

Diagonal [mm]	8k	4k	2k
	Pixel [um]		
8	0.91	1.82	3.6
11	1.25	2.50	5.0
22	2.50	4.99	10.0
24	2.72	5.45	10.9
35	3.97	7.94	15.9
44	4.99	9.99	20.0

Diagonal [mm]	8k	4k	2k
	Nyquist [lp/mm]		
8	551	275	138
11	401	200	100
22	200	100	50
24	184	92	46
35	126	63	31
44	100	50	25

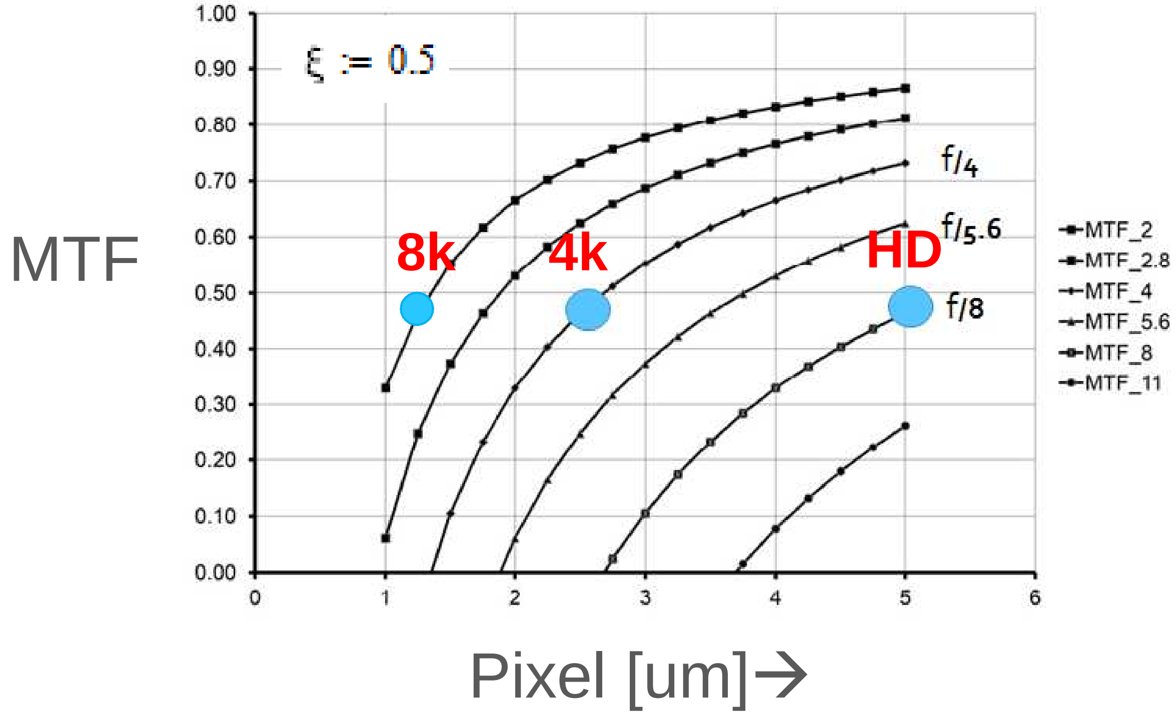
Larry's domain

Lens MTF at Nyquist for different pixels

- For equal number of photons
  - HD f/8 (5.0um pixel)
  - 4k f/4 (2.5um pixel)
  - 8k f/2 (1.25um pixel)
- Also equal MTF

$$\mathrm{MTFlens}(\xi) := \left(1 - 1.22\,\frac{F}{H}\cdot\xi\cdot\lambda\right)$$

When $\xi := 1.6\cdot\frac{H}{F}$ MTF=0



Perceived sharpness

- Otto Schade
- Area under squared (Modulation-Transfer-Function) MTF-curve
  - Normalized spatial frequency (fx) with pixel-pitch/width (H) $\xi := fx \cdot H$

$$\text{Sharpness\_MTF} := \int_0^{0.5} \text{MTF}(\xi)^2 \, d\xi$$

- Nyquist is half the sample frequency $\xi := 0.5$

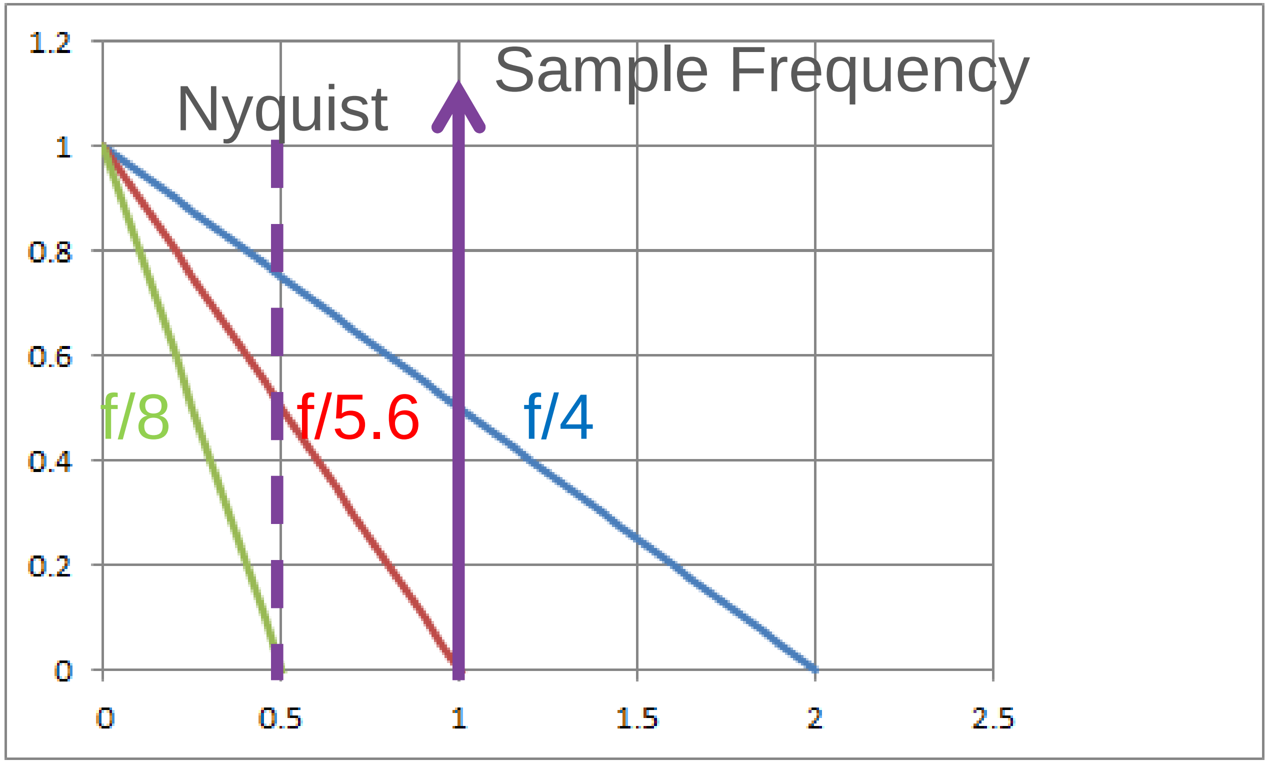
Sharpness

- Normalized spatial frequency (fx) with pixel-pitch/width (H) $\xi := fx \cdot H$
- Optical low pass filter: $MTFolp(\xi) := \left|\cos\left(\frac{\pi}{2}\cdot\xi\right)\right|$
- Pixel aperture: $MTFpixel(\xi) := |sinc(\xi)|$
- Diffractionlimited, lens $MTFlens(\xi) := \left(1 - 1.22\frac{F}{H}\cdot\xi\cdot\lambda\right)$

$$MTF(\xi) := \left|\left(1 - 1.22\frac{F}{H}\cdot\xi\cdot\lambda\right)\cdot sinc(\xi)\cdot\cos\left(\frac{\pi}{2}\cdot\xi\right)\right|$$

- The good news is that olp and pixel aperture also degrade MTF

Diffraction and a 2.5um pixel: 4k in 2/3"

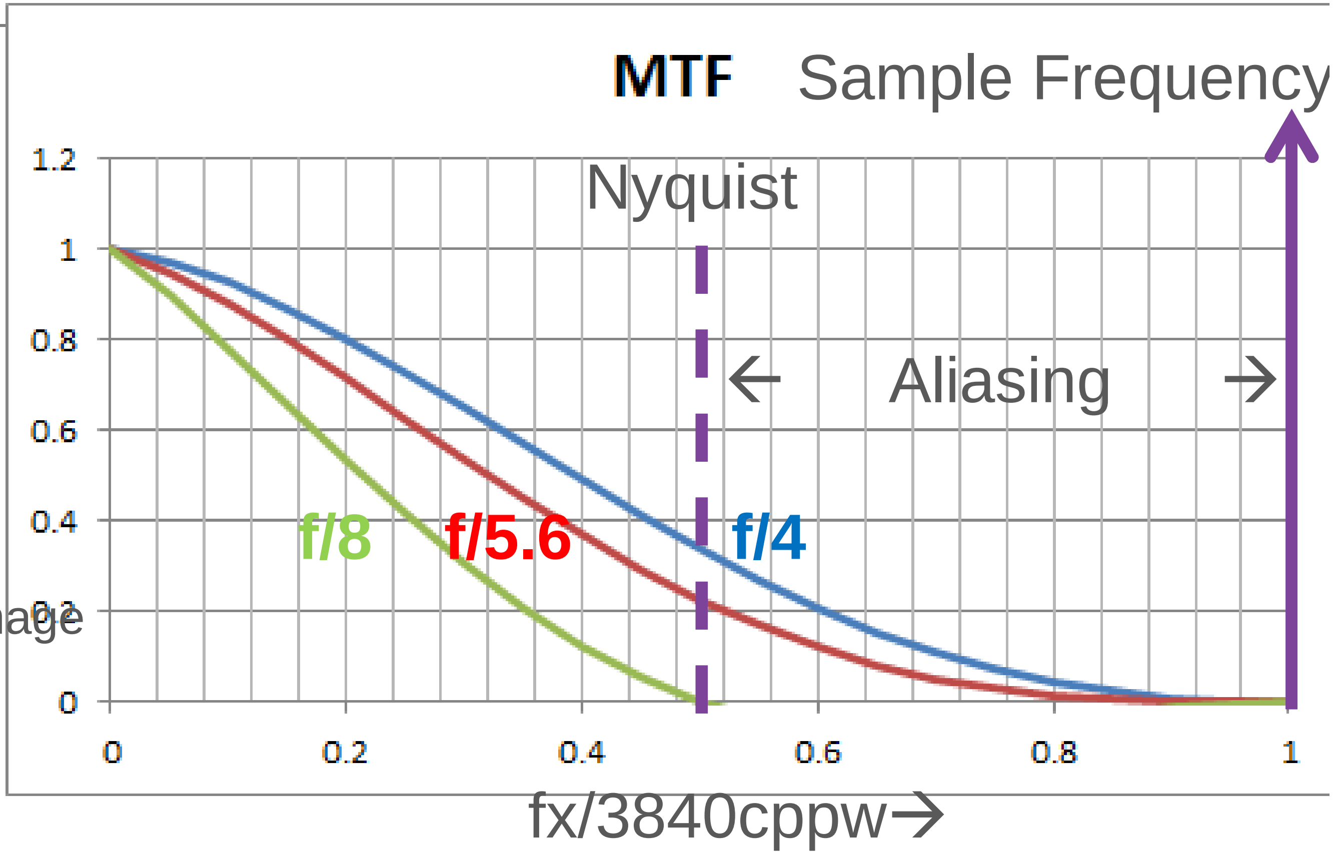


4k in 2/3”

Diffraction, lens
Optical low-pass filter
Pixel aperture

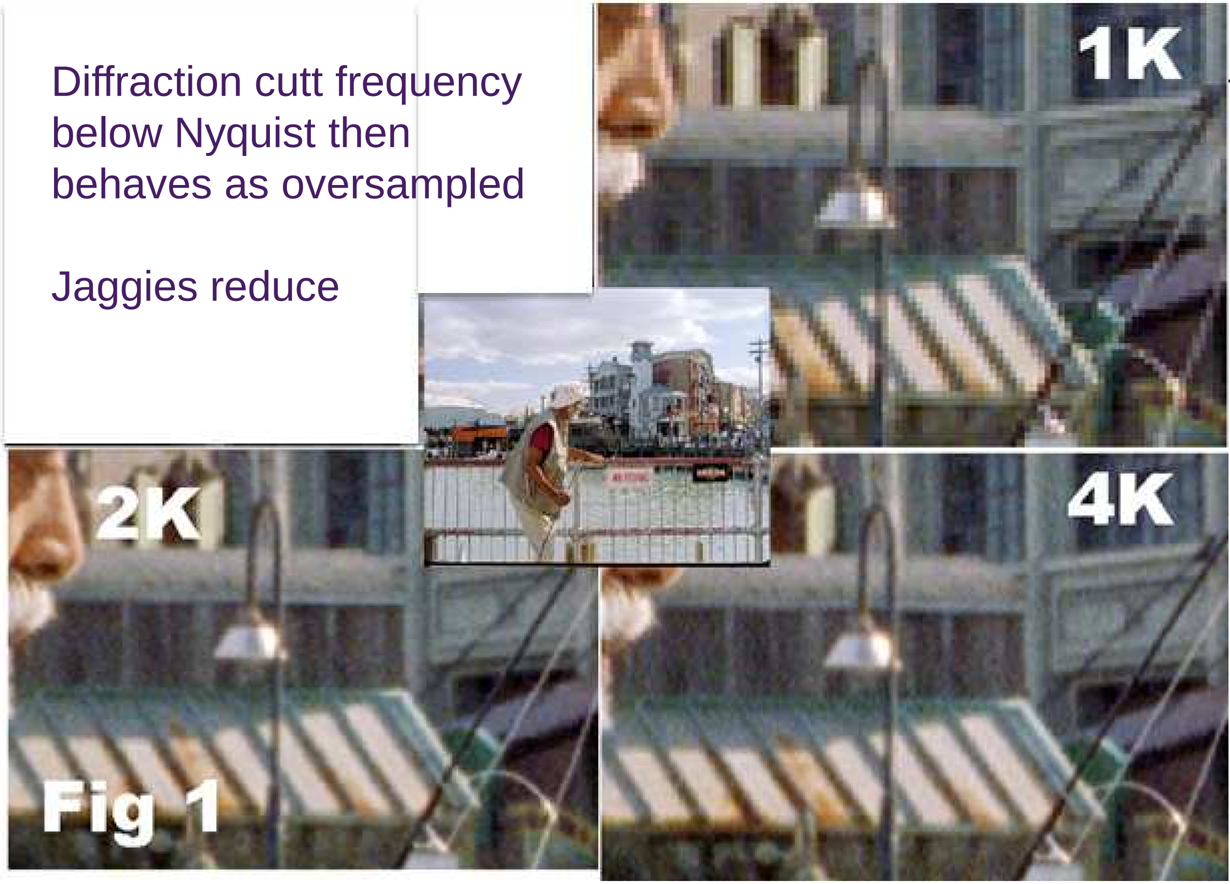
Schade, sharpness_MTF
83%: f/4 (30%)
69%: f/5.6 (25%)
48%: f/8 (17%)
Above f/8 oversampled image

Aperture correction!



Diffraction cutt frequency
below Nyquist then
behaves as oversampled

Jaggies reduce



SMPTE 2001 Sydney Australia, **EVOLUTION OF RESOLUTION IN FILM SCANNERS,** By P R Swinson . Cintel International

Sharpness

- MTF: $$MTF(\xi) := \left| \left(1 - 1.22\frac{F}{H}\cdot\xi\cdot\lambda\right)\cdot \mathrm{sinc}(\xi)\cdot\cos\left(\frac{\pi}{2}\cdot\xi\right)\right|$$ $$\xi := fx\cdot H$$
- **Scaling**
  - **Sharpness utilization is the same when ratio F/H is the same**

$$Sharpness\_MTF := \int_{0}^{0.5} MTF(\xi)^2\, d\xi$$

$$Sharpness\_MTF \; \square \left(\frac{H}{F}\right)$$

$$Sharpness\_MTF \; \square \left(\frac{Diagonal}{F\cdot Resolution}\right)$$

Depth-of-Field

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Depth-of-Field

- Depth-of-Field
- Assumption: Same picture in same format
- The lesser light in, the larger DOF

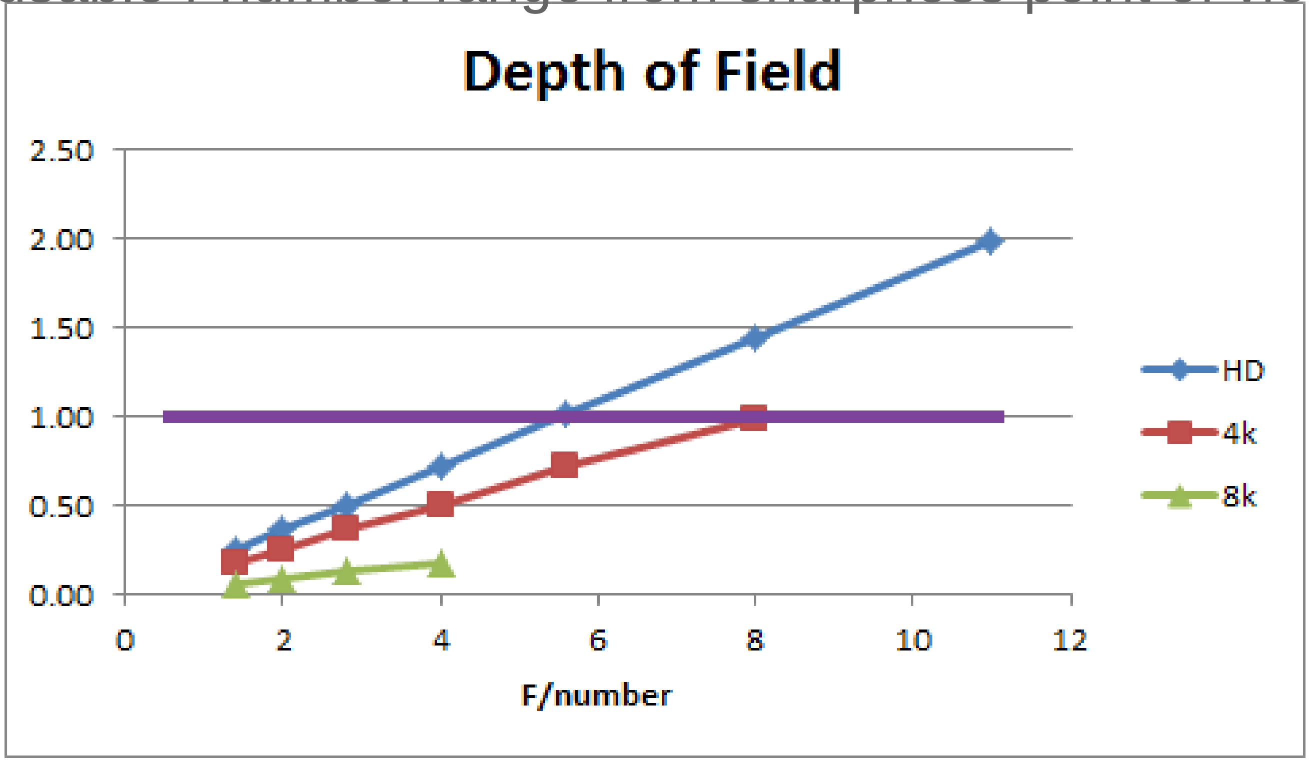
- **Scaling**

$$\mathrm{Depth\_Of\_Field} \;\square\; \frac{1}{\mathrm{Resolution}^2} \cdot \frac{F}{H}$$

$$\mathrm{Depth\_Of\_Field} \;\square\; \frac{F}{\mathrm{Diagonal} \cdot \mathrm{Resolution}}$$

Depth-of-Field in 2/3”

- Only in usable f-number range from sharpness point of view



Summary

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Scaling summary

- Pixelsize = H, f/number of the lens = F, Resolution = 2k , 4k, 8k
- Diagonal is proportional with H*Resolution

$$\text{Sensitivity} \propto \left(\frac{H}{F}\right)^2 \qquad \text{Sharpness\_MTF} \propto \left(\frac{H}{F}\right) \qquad \text{Depth\_Of\_Field} \propto \frac{1}{\text{Resolution}^2} \cdot \frac{F}{H}$$

$$\text{Sensitivity} \propto \left(\frac{\text{Diagonal}}{F \cdot \text{Resolution}}\right)^2 \qquad \text{Sharpness\_MTF} \propto \left(\frac{\text{Diagonal}}{F \cdot \text{Resolution}}\right) \qquad \text{Depth\_Of\_Field} \propto \frac{1}{\frac{\text{Diagonal}}{F \cdot \text{Resolution}}} \cdot \frac{1}{\text{Resolution}^2}$$

11mm

DOF	11	8	5.6	4	2.8	2	1.4
HD	1.98	1.44	1.01	0.72	0.50	0.36	0.25
4k	0.99	0.72	0.50	0.36	0.25	0.18	0.13
8k	0.49	0.36	0.25	0.18	0.13	0.09	0.06

Nyquist limited

sharpness	11	8	5.6	4	2.8	2	1.4
HD	504.23	633.80	758.70	852.46	928.29	981.47	1022.73
4k	514.61	707.58	993.28	1267.59	1517.40	1704.93	1856.59
8k	514.61	707.58	1010.83	1415.17	1986.56	2535.19	3034.80

Diffraction limited

#photons/pixel	11	8	5.6	4	2.8	2	1.4
HD	1.00	1.90	3.87	7.58	15.48	30.34	61.92
4k	0.25	0.47	0.97	1.90	3.87	7.58	15.48
8k	0.06	0.12	0.24	0.47	0.97	1.90	3.87

Noise reduction

33mm

DOF	11	8	5.6	4	2.8	2	1.4
HD	0.66	0.48	0.34	0.24	0.17	0.12	0.08
4k	0.33	0.24	0.17	0.12	0.08	0.06	0.04
8k	0.16	0.12	0.08	0.06	0.04	0.03	0.02

sharpness	11	8	5.6	4	2.8	2	1.4
HD	873.05	937.01	990.54	1027.39	1055.64	1074.76	1089.26
4k	1333.20	1547.49	1737.81	1874.02	1981.08	2054.78	2111.28
8k	1543.78	2068.67	2639.68	3094.98	3475.63	3748.04	3962.15

#photons/pixel	11	8	5.6	4	2.8	2	1.4
HD	9.03	17.07	34.83	68.26	139.32	273.06	557.26
4k	2.26	4.27	8.71	17.07	34.83	68.26	139.32
8k	0.56	1.07	2.18	4.27	8.71	17.07	34.83

The good news

- Surprise
  - The following combination of pixel-size and f/number results in the same sensitivity (SNR) and sharpness utilization:
  - In 2/3” = 11mm
    - 2k pixels of 5um af f/11
    - 4k pixels of 2.5um at f/5.6
    - 8k pixels 1.25um at f/2.8.
  - But also in 44mm
    - 8k pixels of 5um af f/11
    - 16k pixels of 2.5um at f/5.6

The bad news for sports and the good news for drama

- DOF goes down dramatically
  - Fast focussing difficult in sports
  - In 2/3” = 11mm
    - – 2k pixels of 5um af f/11 DOF=y
    - – 4k pixels of 2.5um at f/5.6 DOF=y/4
    - – 8k pixels 1.25um at f/2.8 DOF=y/16
  - And in 44mm
    - – 8k pixels of 5um af f/11 DOF=y/16
    - – 16k pixels of 2.5um at f/5.6 DOF=y/64
    - – 32k pixels 1.25um at f/2.8. DOF=y/256

What can one do for sports

- Accept more noise in black (readnoise) and in grey (shotnoise)
- Now the lens can be closed further
  - Lesser photons on the pixel, 6dB/f-stop
  - SNR reduces 6dB/f-stop
  - Sharpness reduces. Diffraction cutt frequency halves per 2f-stop's.
- When $\frac{H}{F} := 0.318$ then MTF=0 at Nyquist
- Sharpness can be enhanced
  - Increases noise again, noise reducer has to do more
  - When the diffraction cutt is below Nyquist no correction possible

$$\text{Sensitivity} \; \square \; \left(\frac{H}{F}\right)^2$$

$$\xi := 1.6 \cdot \frac{H}{F}$$

To be continued….

Questions