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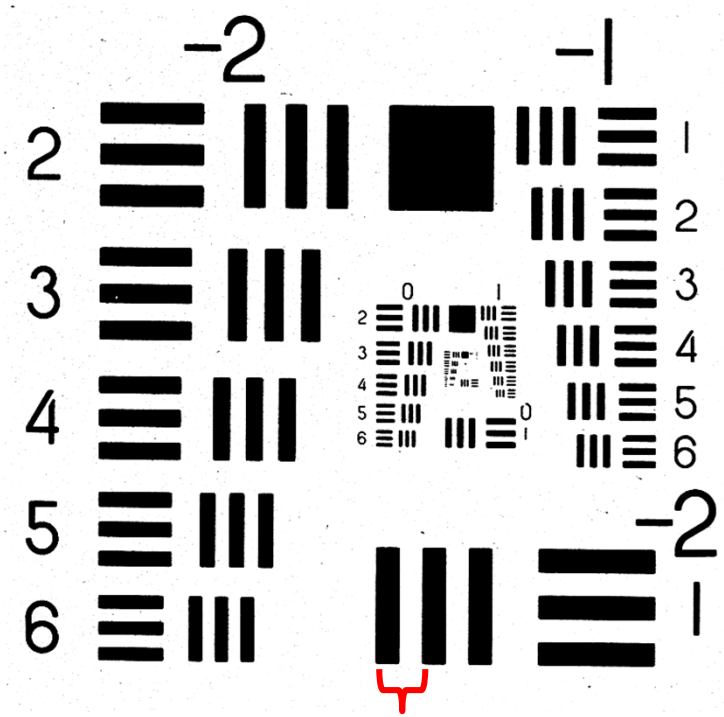
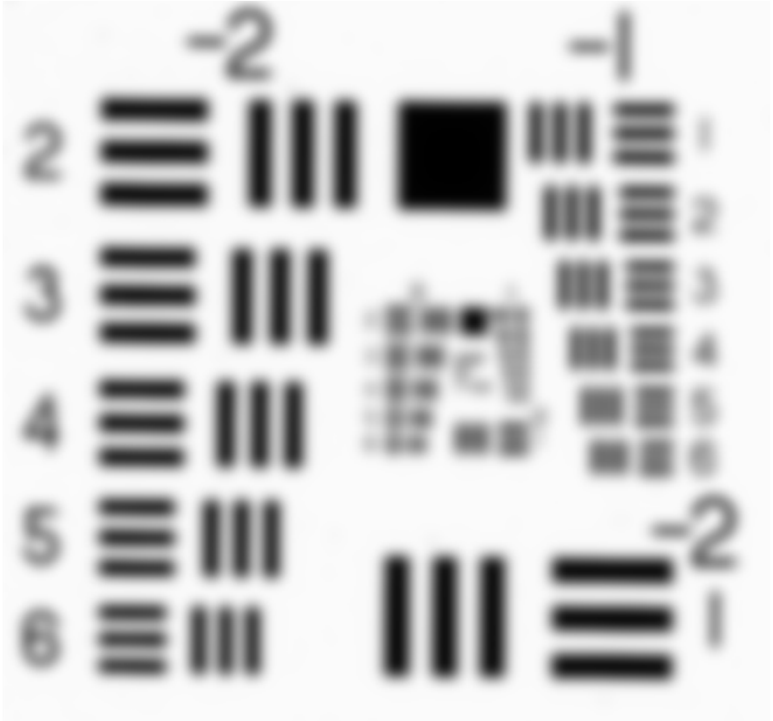
Resolution test with line patterns

OBJECT



1 line pair

IMAGE



Resolution limit is usually given in line pairs per mm in sensor plane.

Visual evaluation usually.

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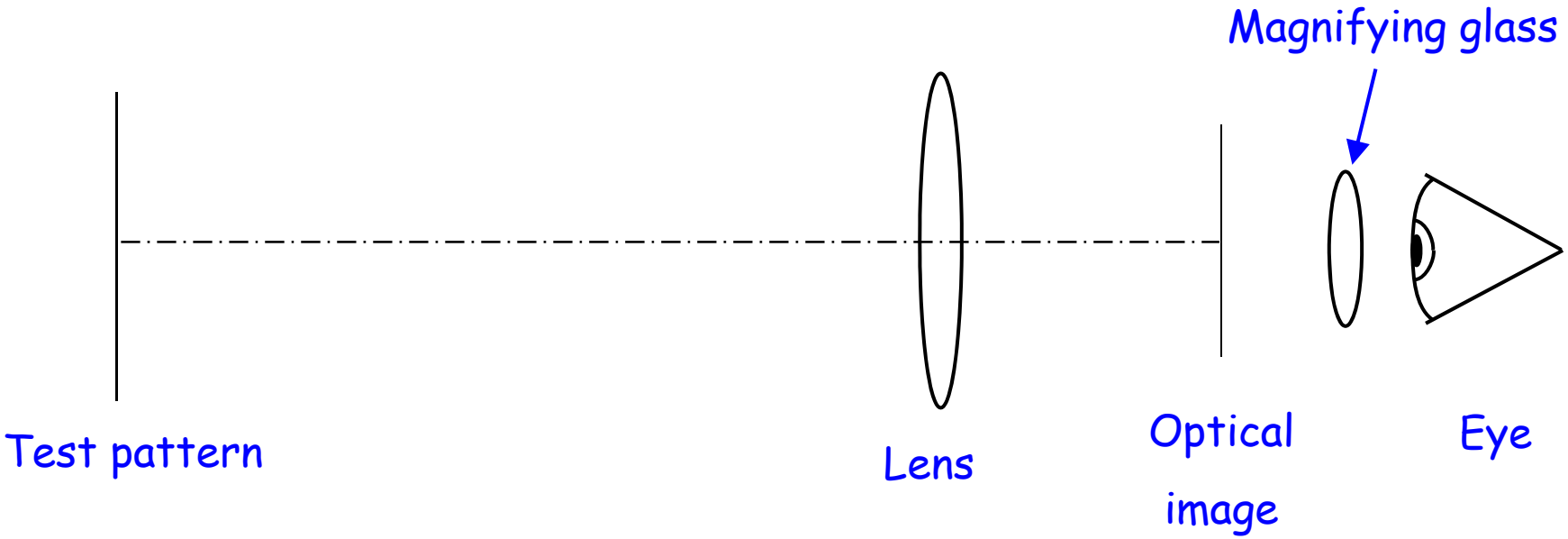
Test of optics alone



This gives the resolution of the optics, R_{optics}

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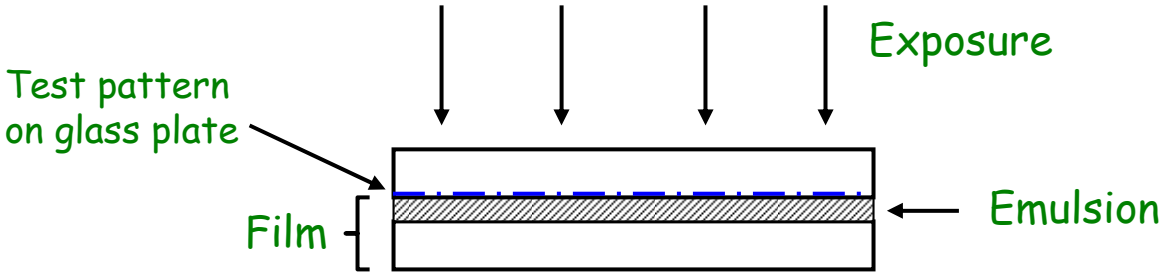
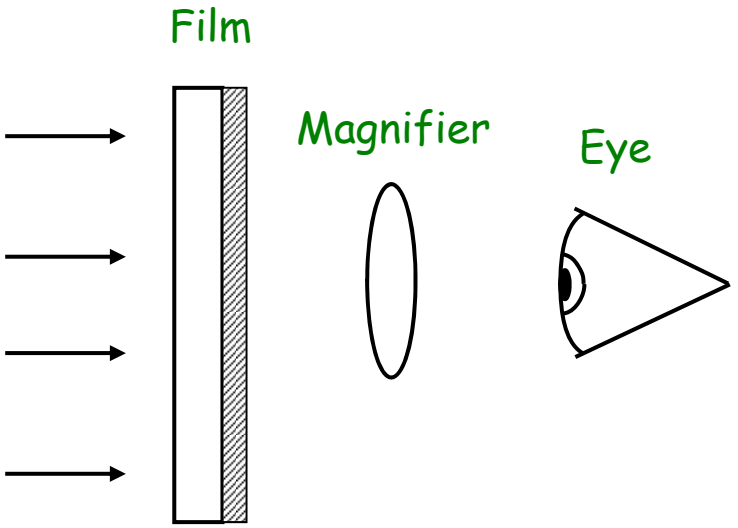
Test of film alone



Development



This gives R_{film}

Rule of thumb: $$\frac{1}{R_{total}} \approx \frac{1}{R_{optik}} + \frac{1}{R_{film}}$$

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It's difficult to measure resolution of electronic sensors

Use "back-calculation"

$$\frac{1}{R_{total}} \approx \frac{1}{R_{optik}} + \frac{1}{R_{sensor}}$$

From experiment

Calculated

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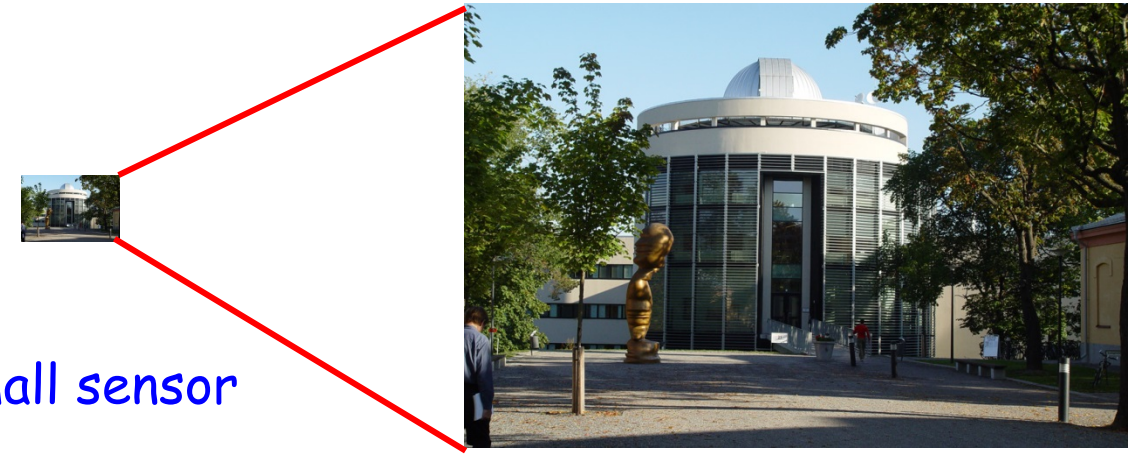
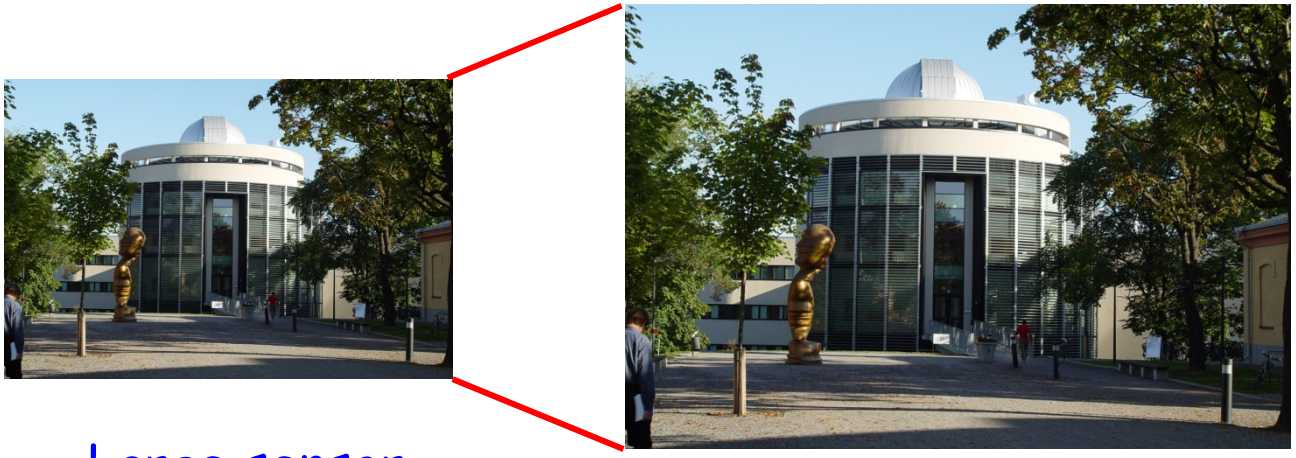
Sensor size matters!



Small sensor

Final image



Large sensor

Final image

Higher resolution needed for small sensor!

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Solution

Give resolution in “line pairs per picture height”.

Numbers directly comparable regardsless of sensor size, megapixels etc.

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Resolution tests

Advantages: Cheap, simple, easy to understand

Disadvantages: Subjective, limited information

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Resolution numbers don't tell you everything!

Which image would you prefer, a or b?

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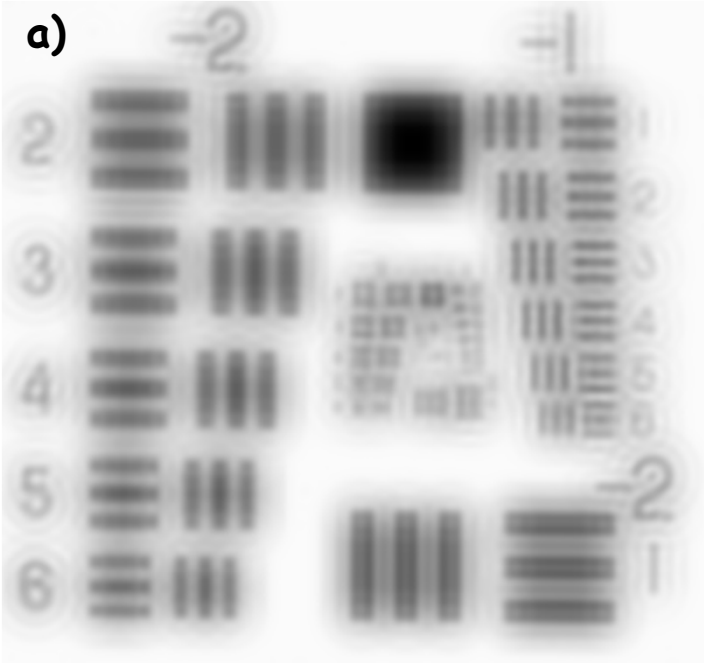
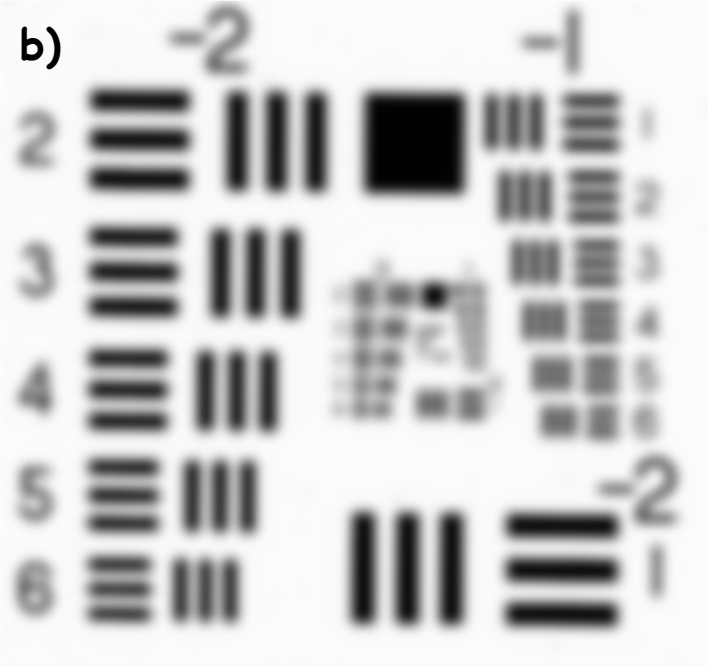
Actually, the resolution is 60 % higher in a than in b!!

You don't believe that?

Let's look at a test pattern imaged with cameras a and b





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MTF (Modulation Transfer Function)

Advantages: Objective

Gives a lot of information

Disadvantages: Complicated

Expensive

Idea: Image line patterns of different densities.

How much lower is the contrast in the image compared with the object?

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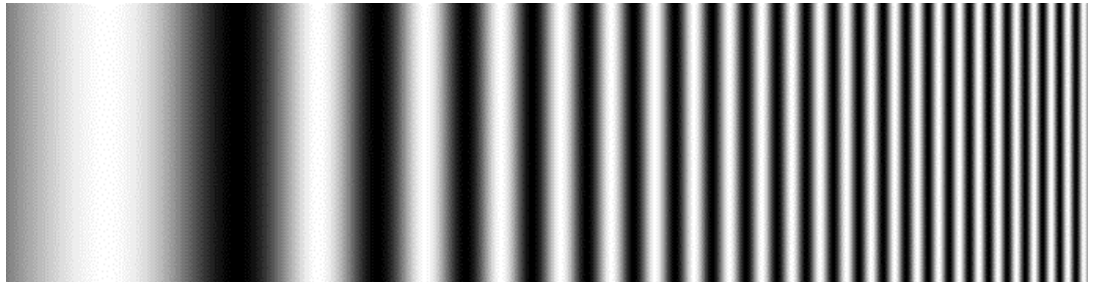
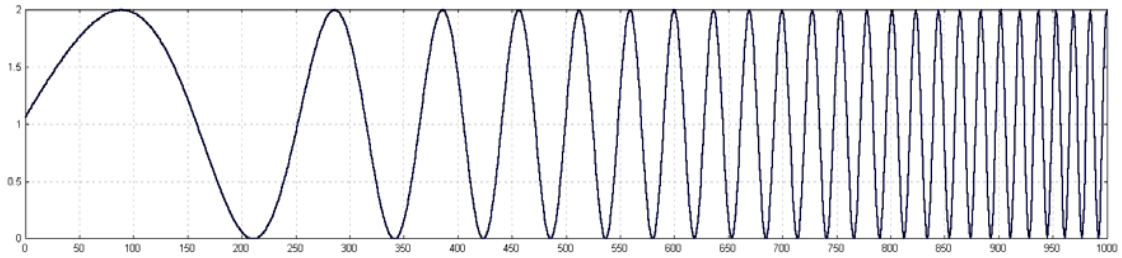
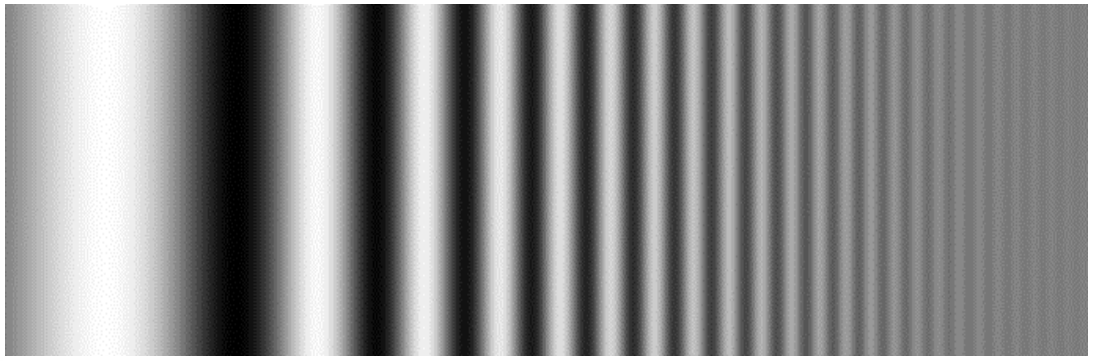
MTF (Modulation Transfer Function)



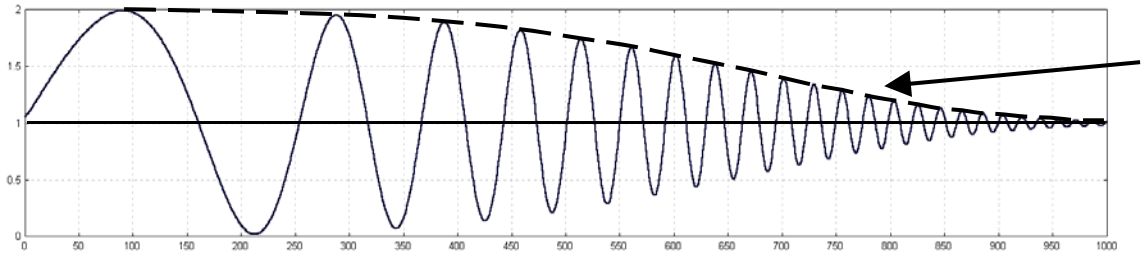
Line pattern in object



Gray level profile



Line pattern in image



MTF curve

Gray level profile

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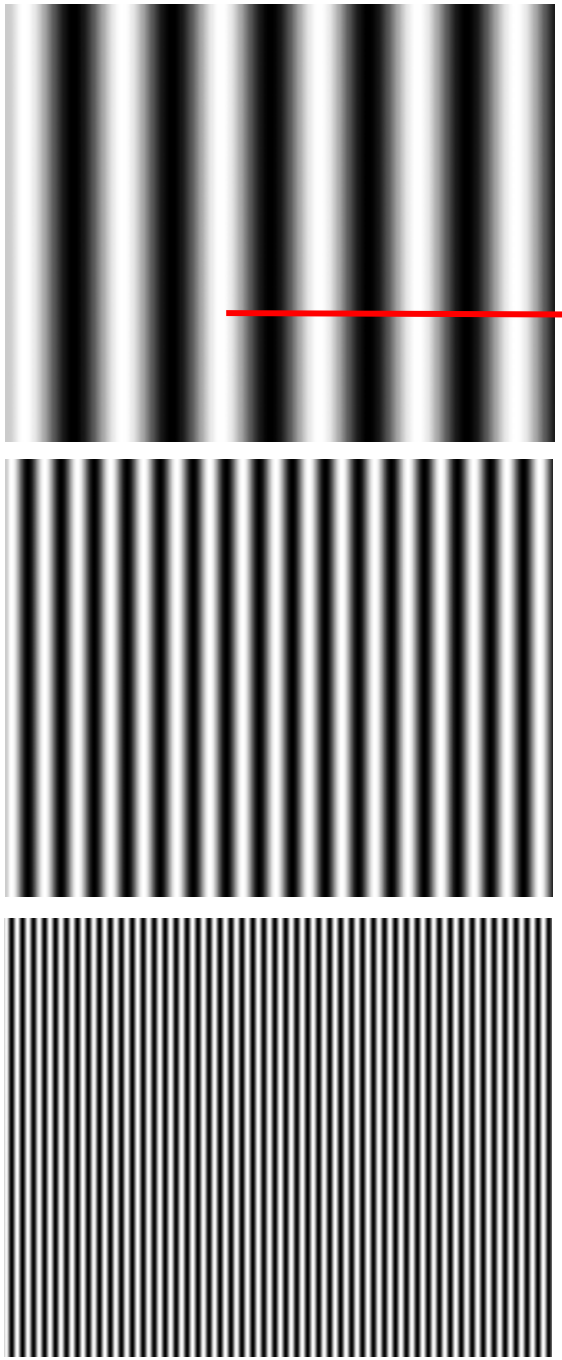
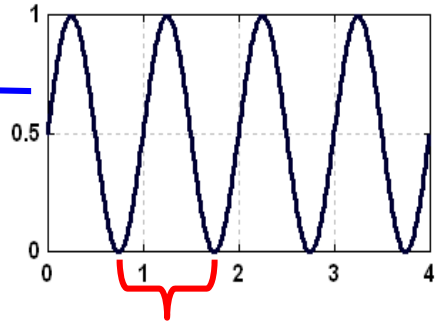
Test patterns with gray level that varies sinusoidally



We need to quantify pattern density



s_0

Spatial frequency (sv. Ortsfrekvens) = $\frac{1}{s_0}$

(= pattern density)

Unit m^{-1} (or mm^{-1})

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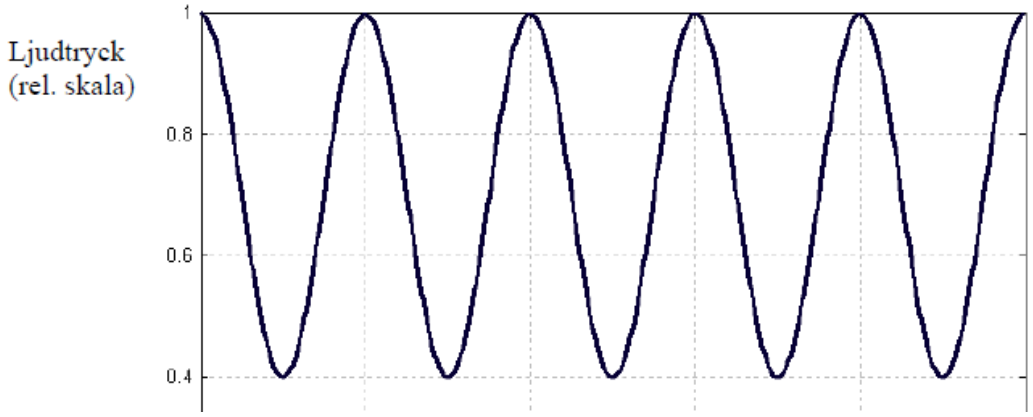
On the website of the course

Introduktion till begreppet ortsfrekvens

Denna lilla skrift har tillkommit för att förklara begreppet ortsfrekvens, samt ge några exempel på beräkningar och omvandlingar som man kan behöva göra när man jobbar med ortsfrekvenser.

1. Vad är ortsfrekvens?

I ljudsammanhang pratar man ofta om olika frekvenser. Det mänsliga örat kan t.ex. uppfatta frekvenser mellan ca. 20 och 20 000 Hz (med åldern minskar detta intervall). Sådana ljudfrekvenser är bekanta begrepp för oss, och vi handskas naturligt och obesvärat med dom. Enheten Hertz (Hz) betyder ”svängningsperioder per sekund”. Hz är alltså samma sak som ”per sekund” = $\frac{1}{s} = s^{-1}$. Figuren nedan visar hur ljudtrycket varierar med tiden för en ton med frekvensen $f = 10$ Hz. Periodtiden för en svängning är i detta fall $T = \frac{1}{f} = 0.10\,\text{s}$.



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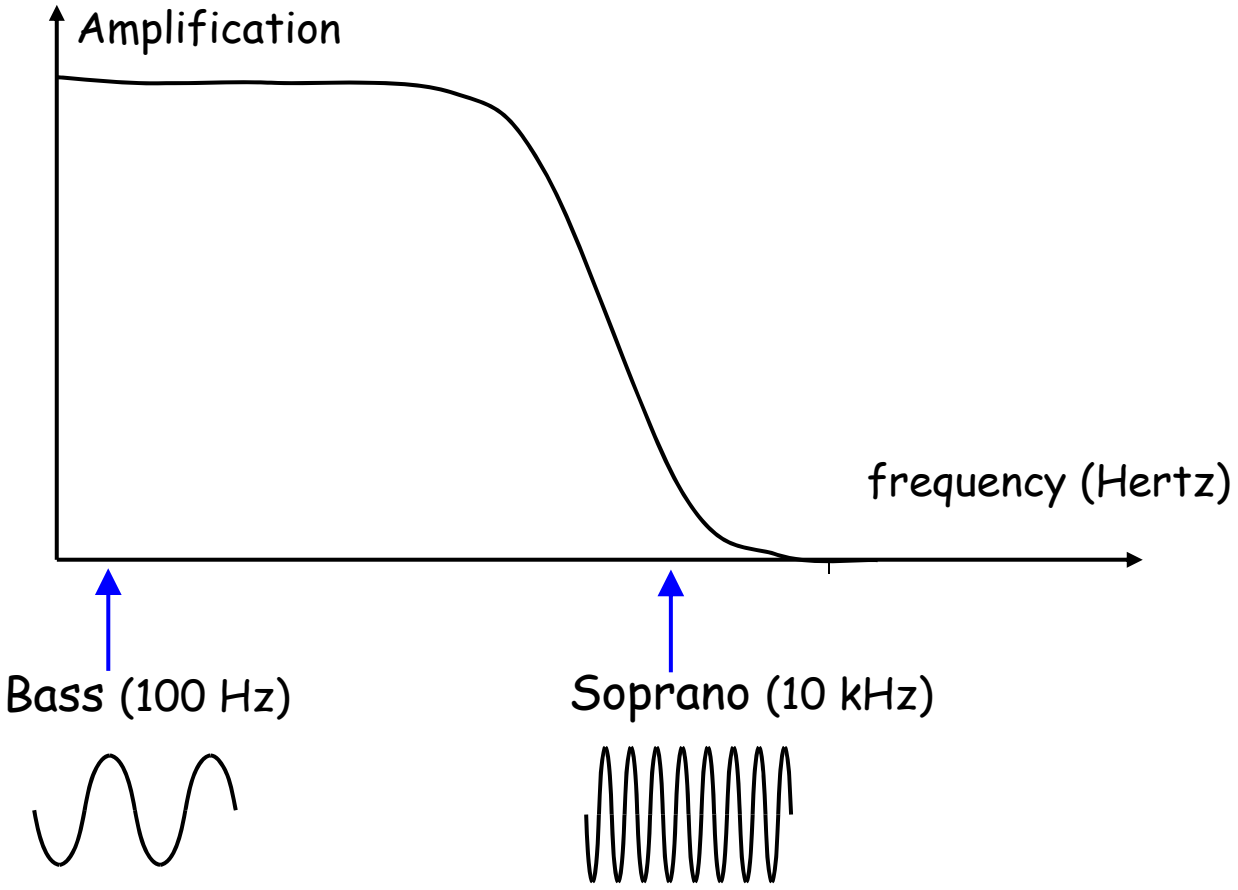
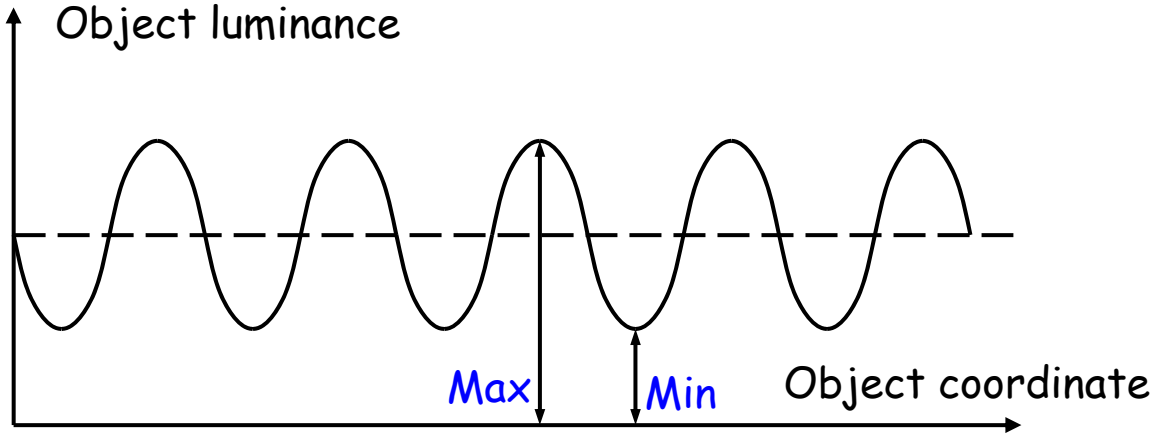
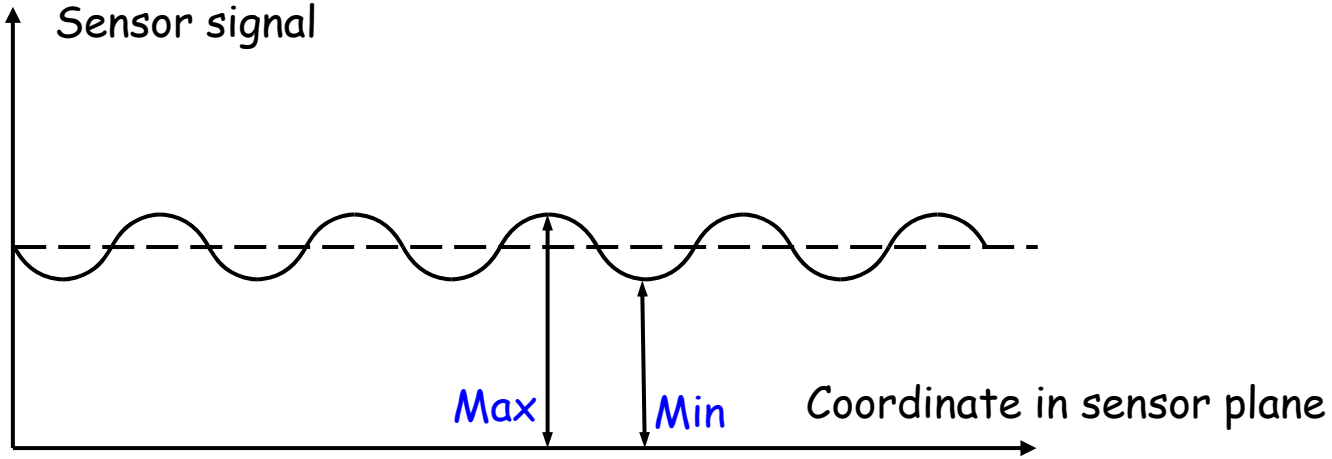
Analogy: Frequency response of an audio amplifier or loudspeaker





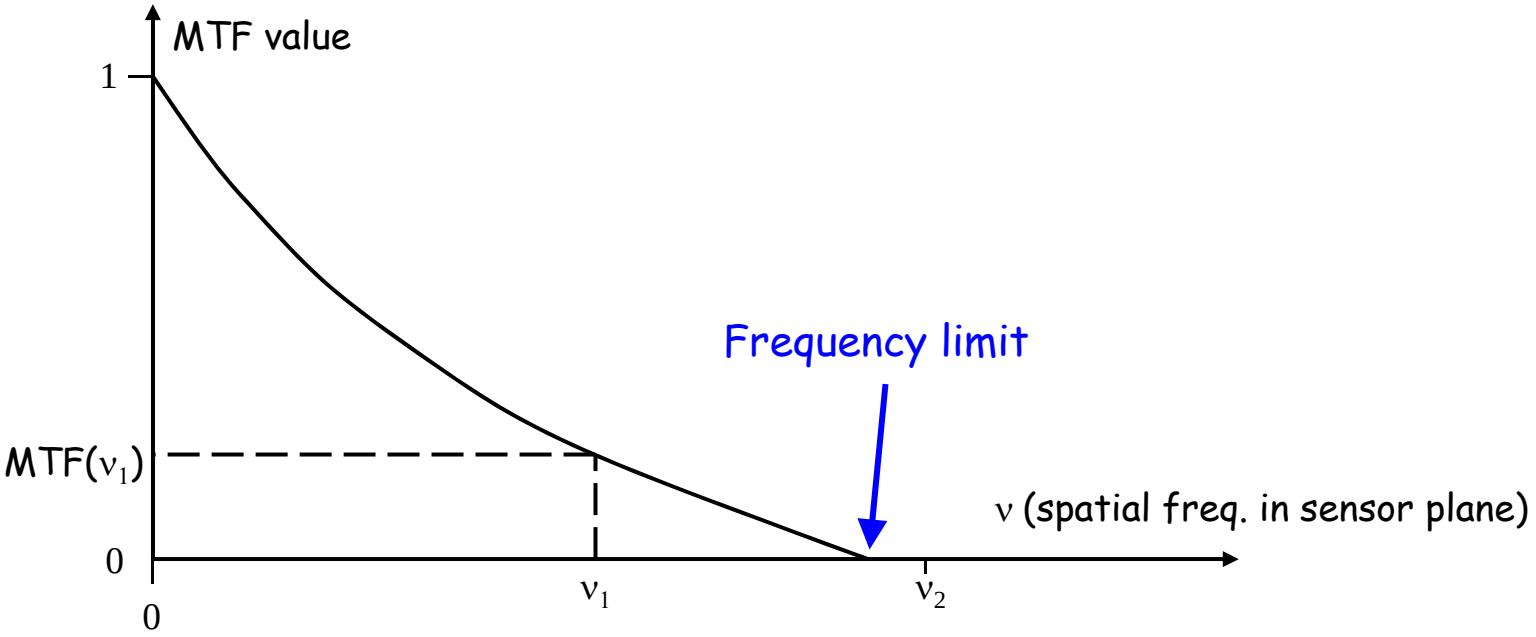
Degree of modulation, $M = \frac{Max - Min}{Max + Min}$ (= ”Contrast”)



$M_{image} < M_{object}$ (loss of contrast)

MTF-value = M_{image}/M_{object}

An MTF curve shows contrast loss as a function of pattern density

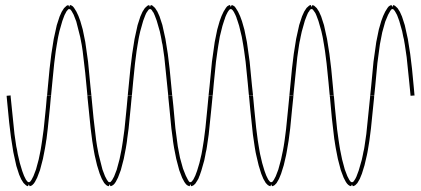


Object

Image

Freq. ν_1:

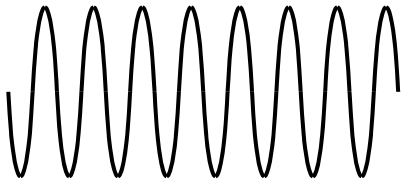
$M = M_1$



$M_{image} = M_1 \times MTF(\nu_1)$

Freq. ν_2:

$M = M_2$



$M_{image} = M_2 \times MTF(\nu_2) = 0$

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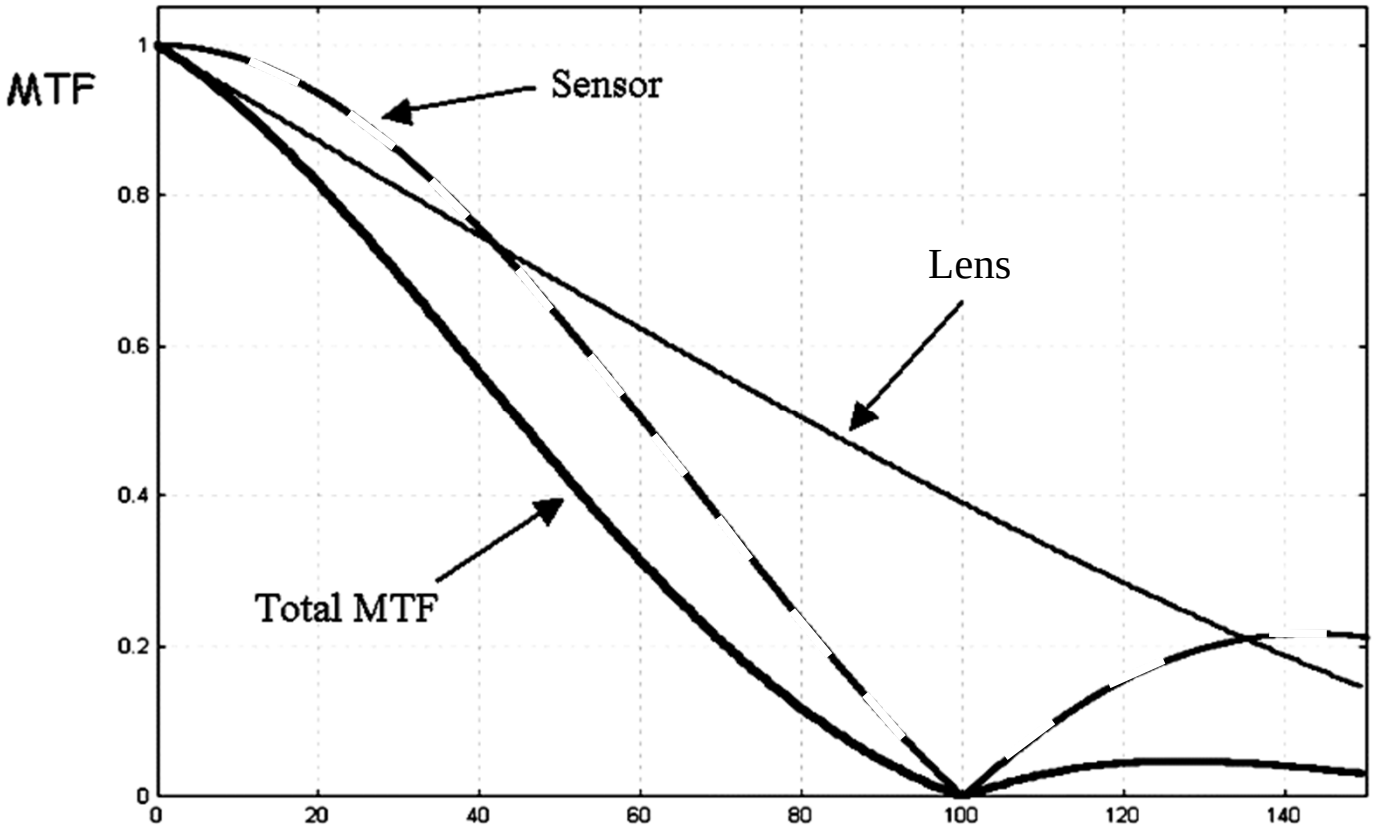
Multiplication rule for MTF

$$MTF_{total} = MTF_{optics} \cdot MTF_{sensor} \cdot MTF_{motion\ blur} \cdot \ldots$$



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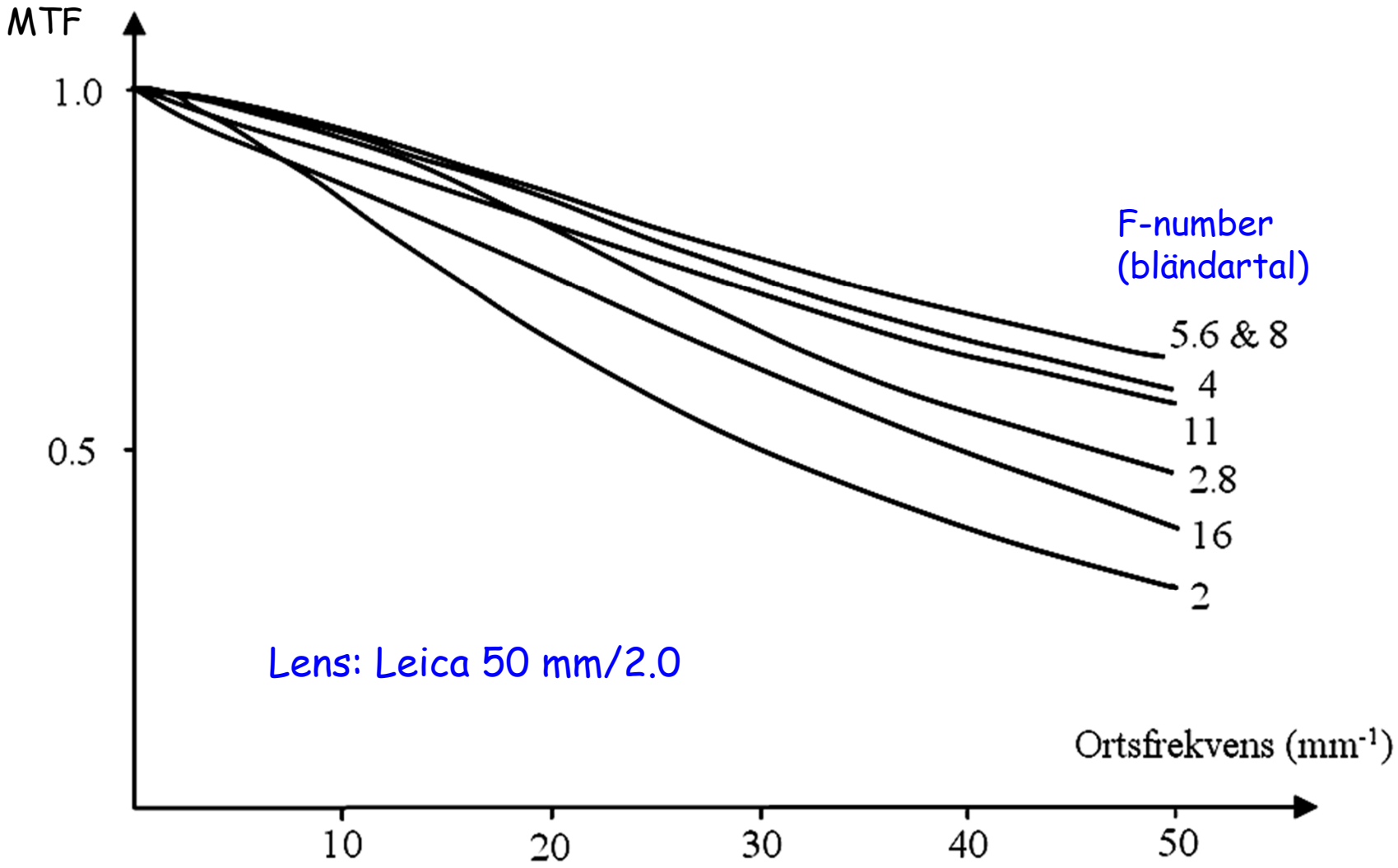
MTF depends on F-number



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Resolution numbers don't tell you everything!

The resolution is 60 % higher in a than in b!!

Let's look at MTF

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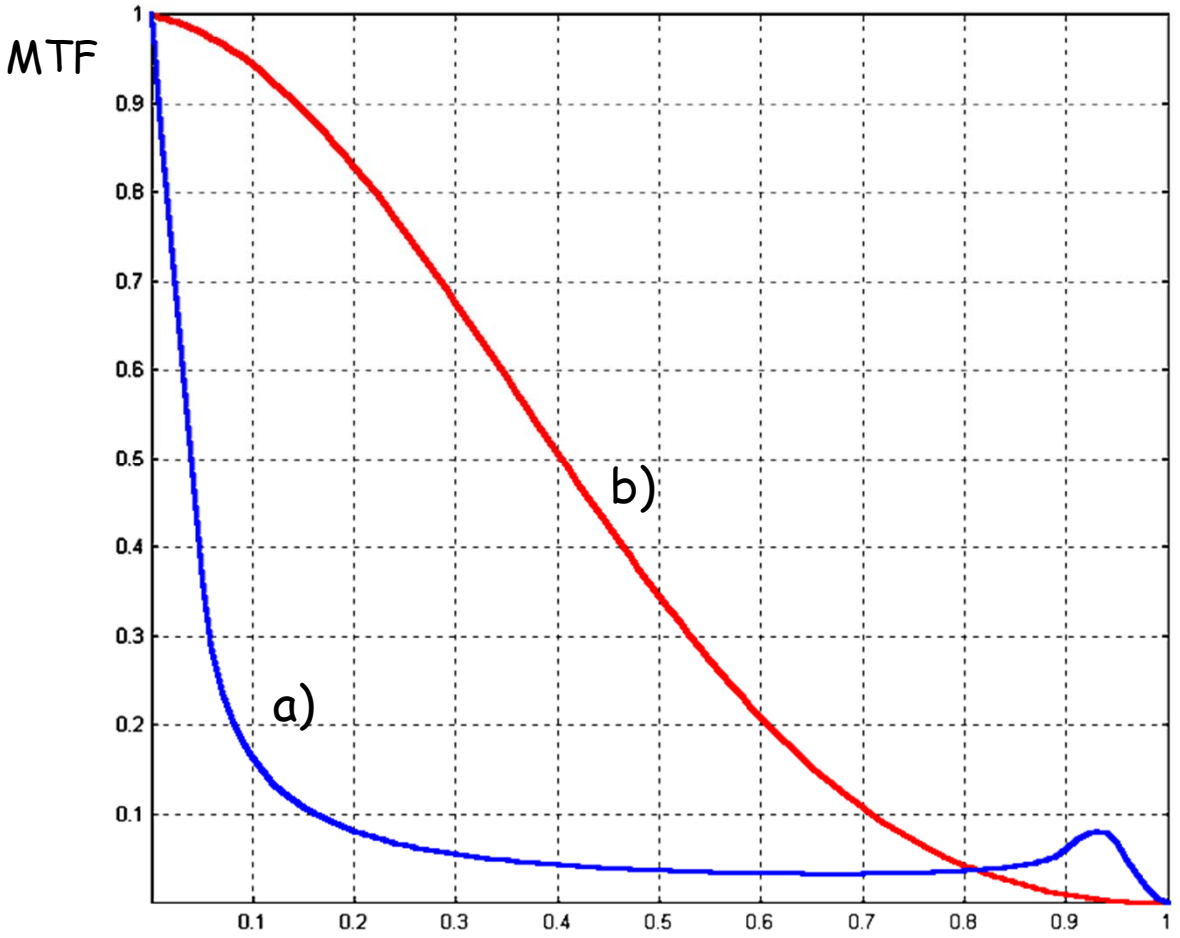
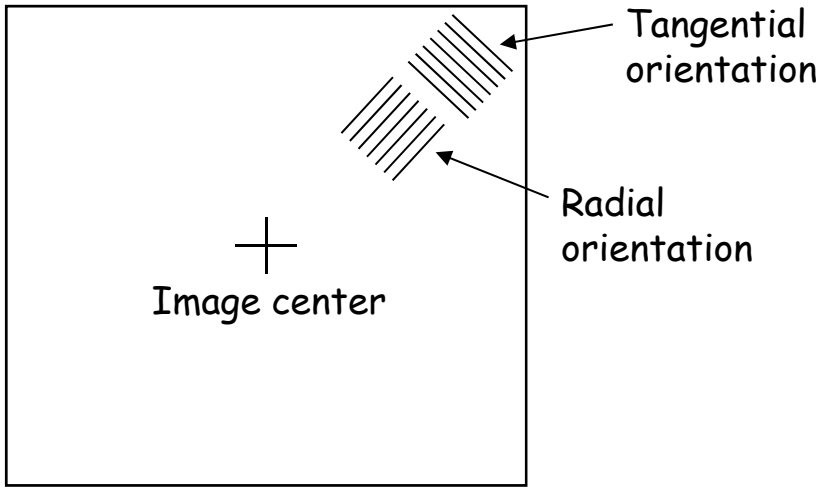
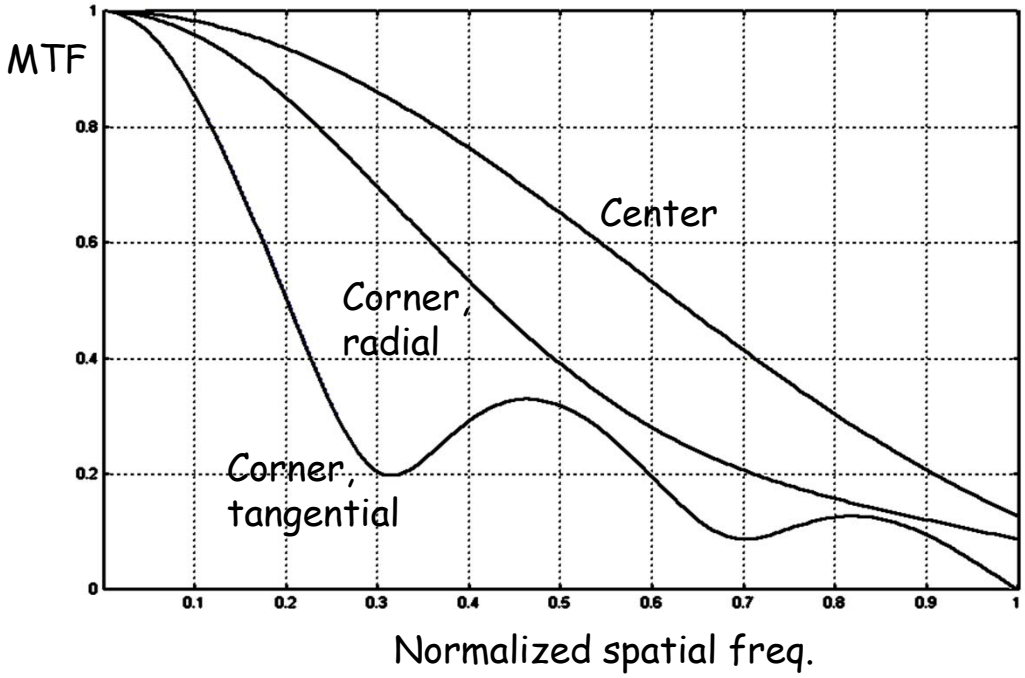
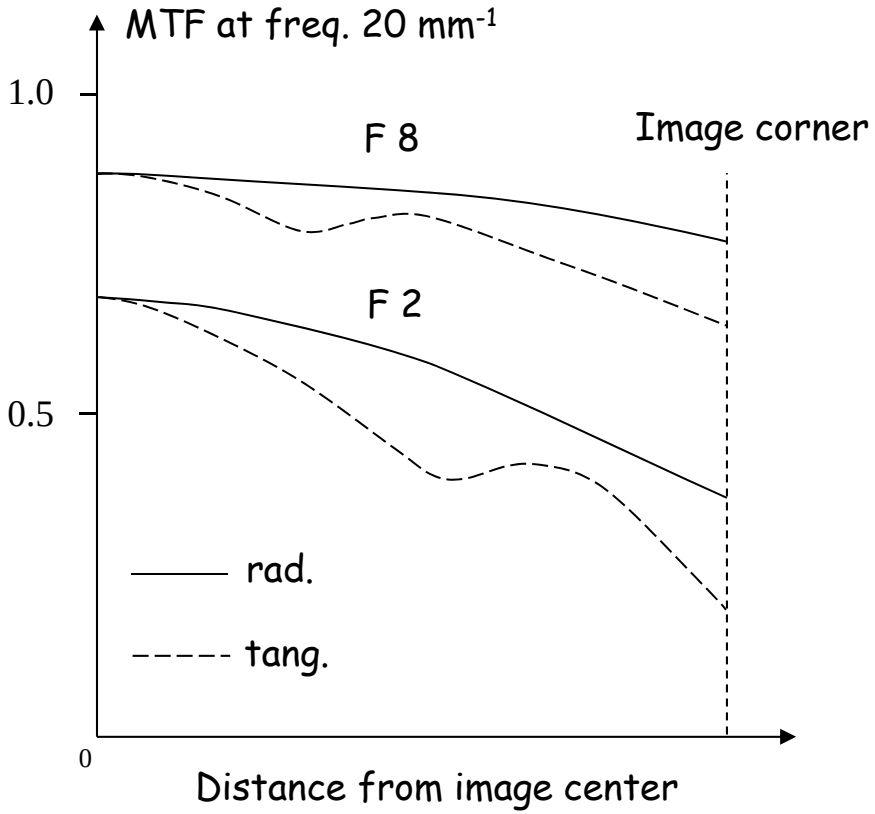
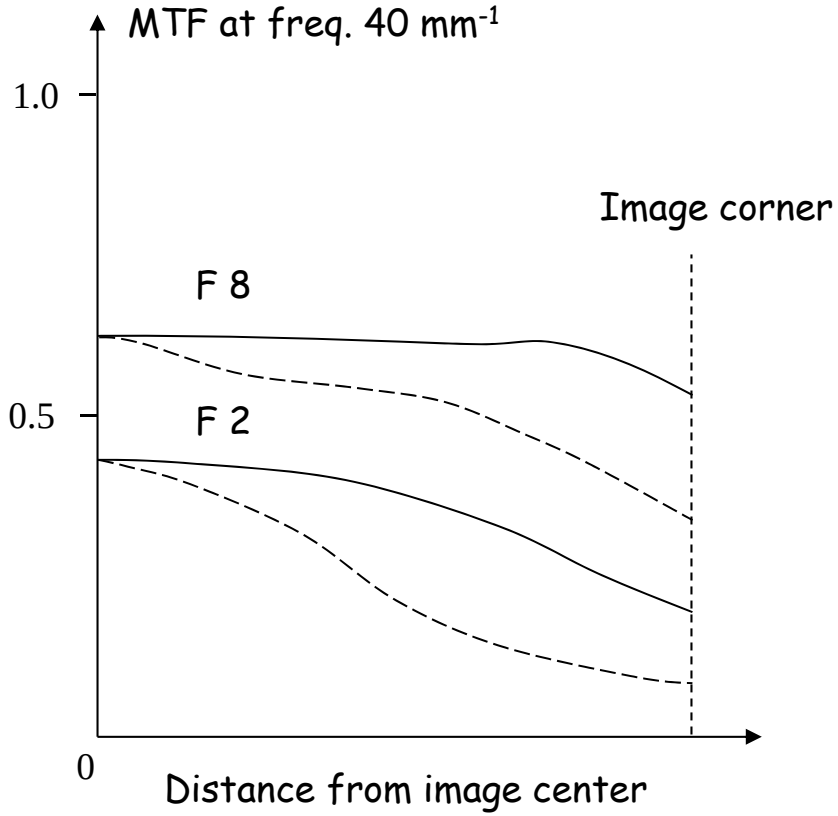



Tangential
orientation
Radial
orientation
Image center


MTF
1
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Center
Corner,
radial
Corner,
tangential
Normalized spatial freq.


MTF at freq. 20 mm-1
1.0
0.5
0
F 8
F 2
Image corner
rad.
tang.
Distance from image center


MTF at freq. 40 mm-1
1.0
0.5
0
F 8
F 2
Image corner
Distance from image center

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MTF for photographic film

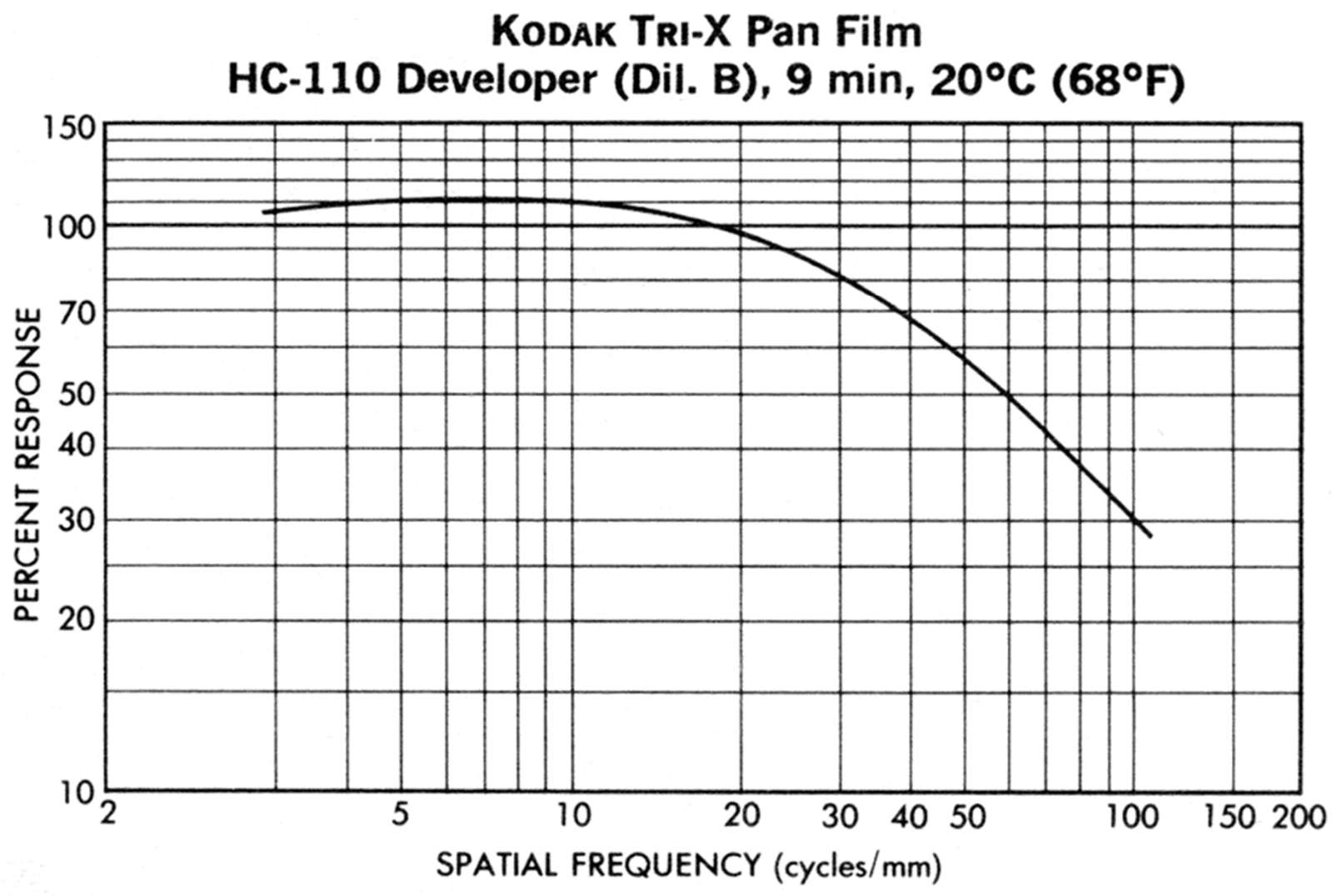

Figure credit: Kodak

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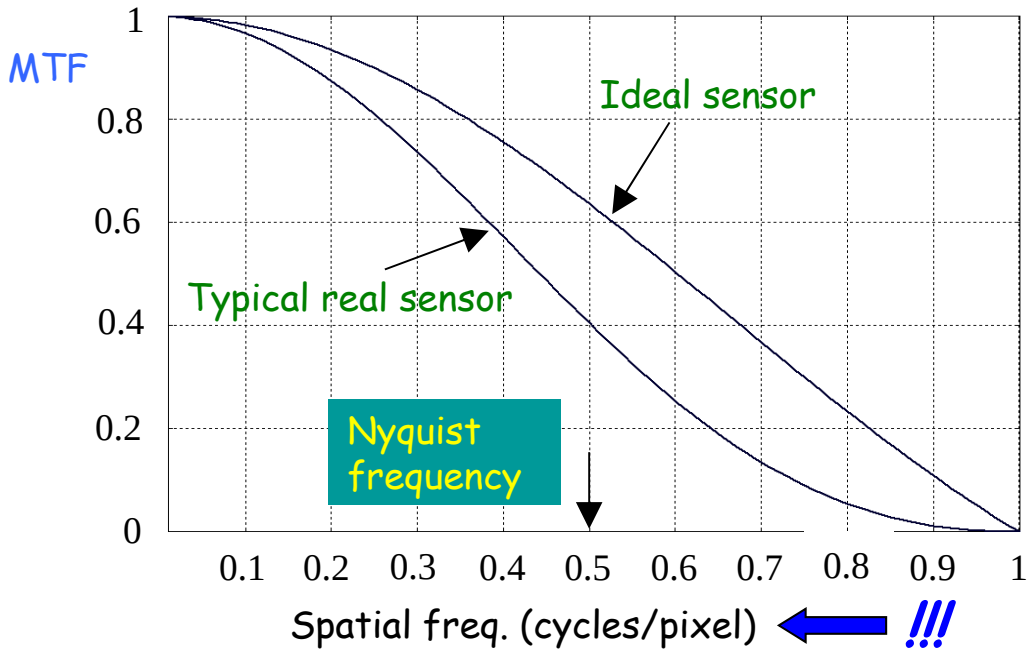
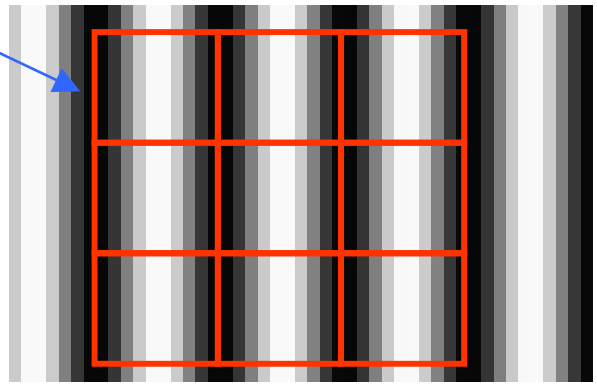
MTF for electronic sensors

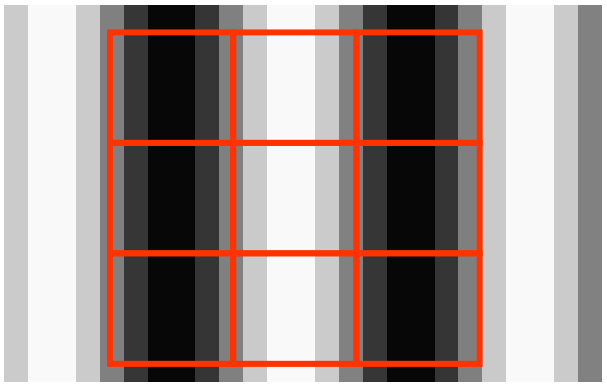


Detector element (pixel).
Typically 2-8 μm wide

1 cycle/pixel



0.5 cycles/pixel



Nyquist freq. = Highest freq. that can be recorded without aliasing (moiré)

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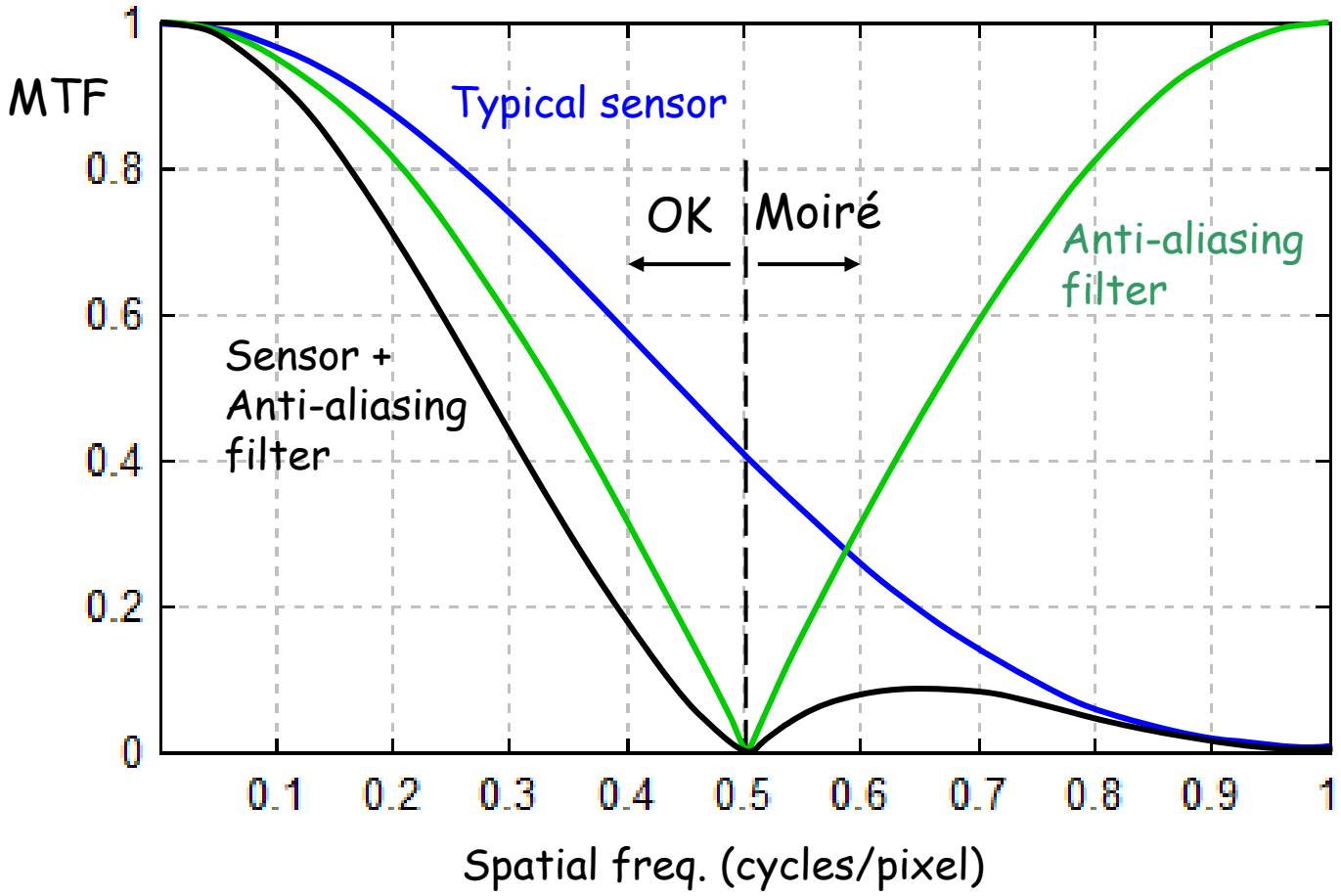
Anti-aliasing filter



Result: Much less moiré effects (but they don't disappear completely)

AND the filter blurs the image considerably!!

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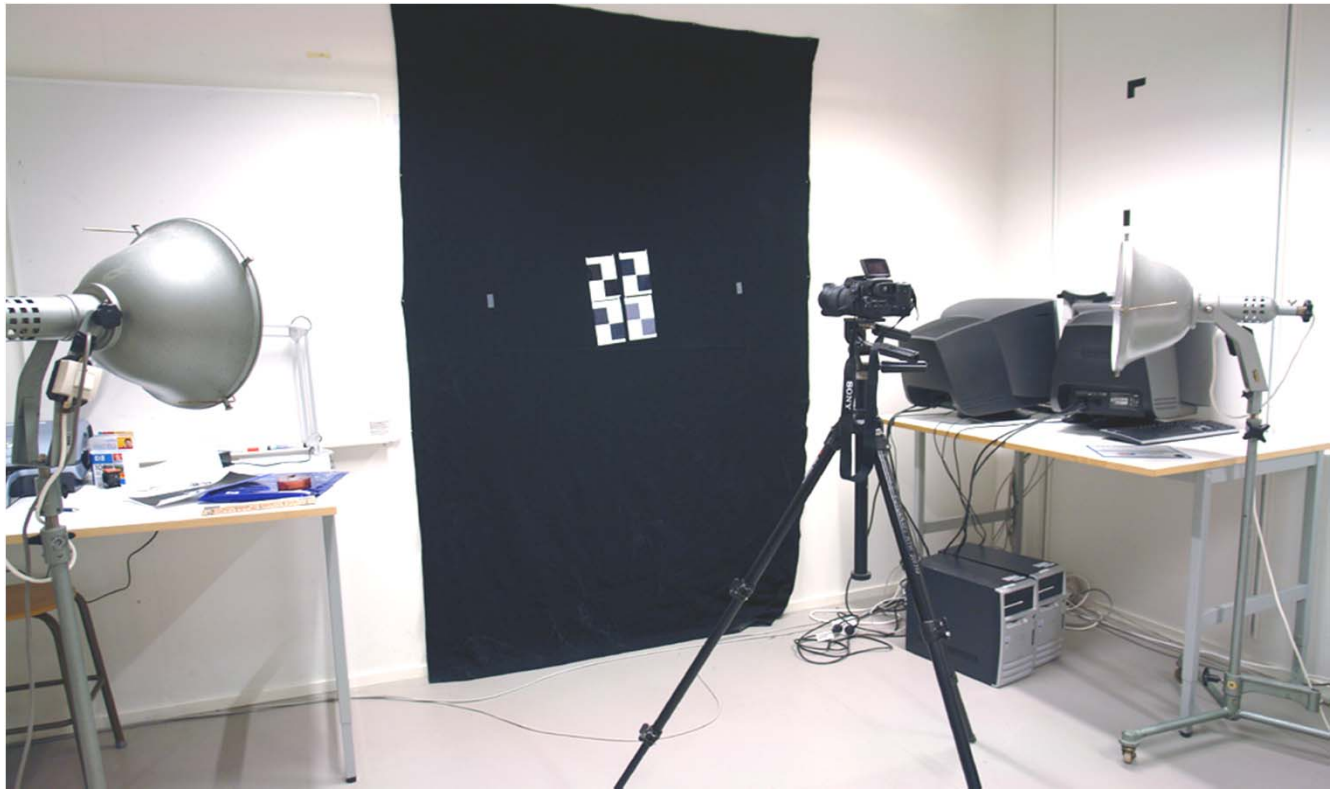
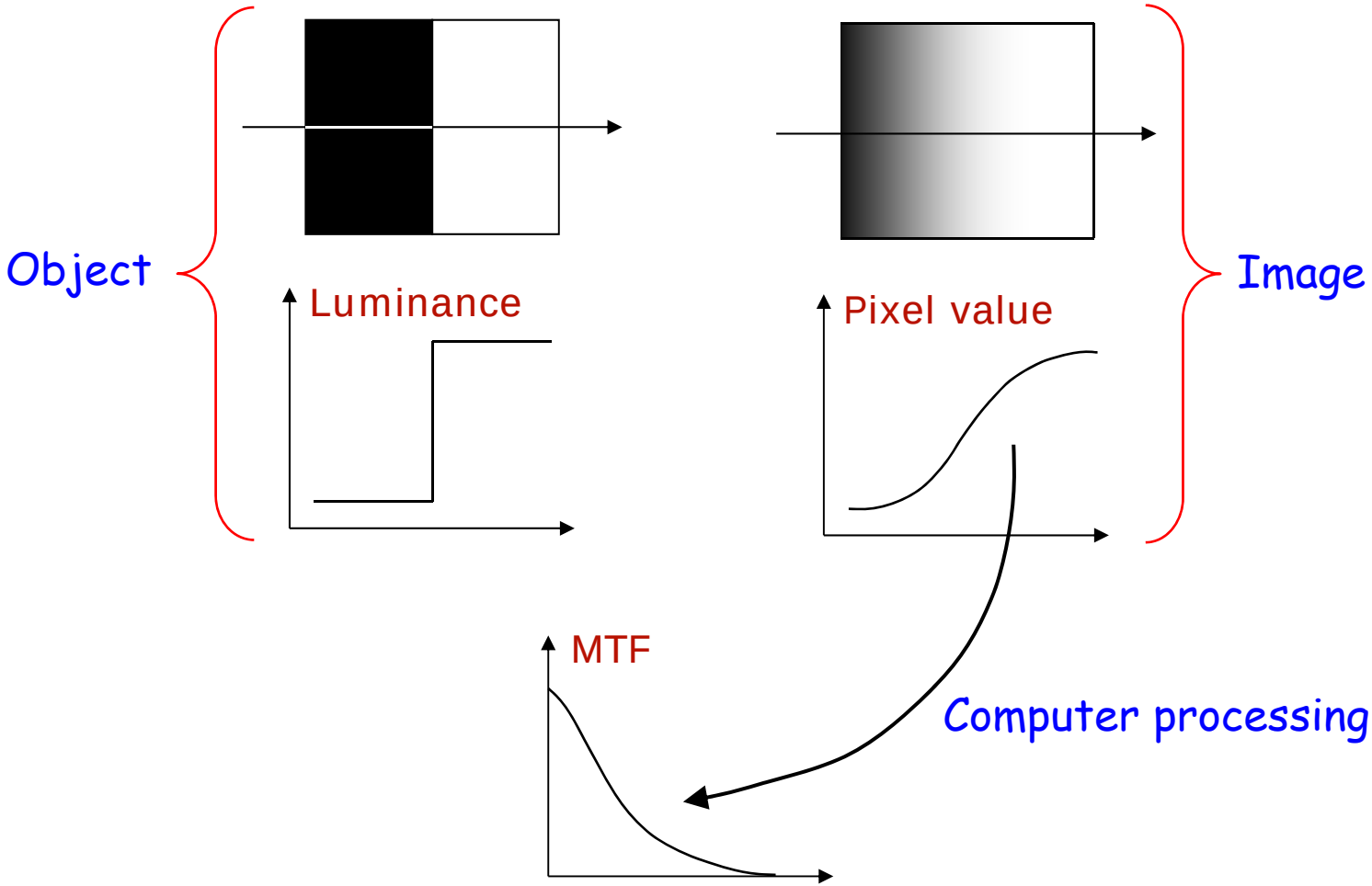
Measuring MTF for digital cameras.



Photograph edge (avoid sharpening, use RAW format)
+ computer processing.


Object
Luminance
Pixel value
Image
MTF
Computer processing

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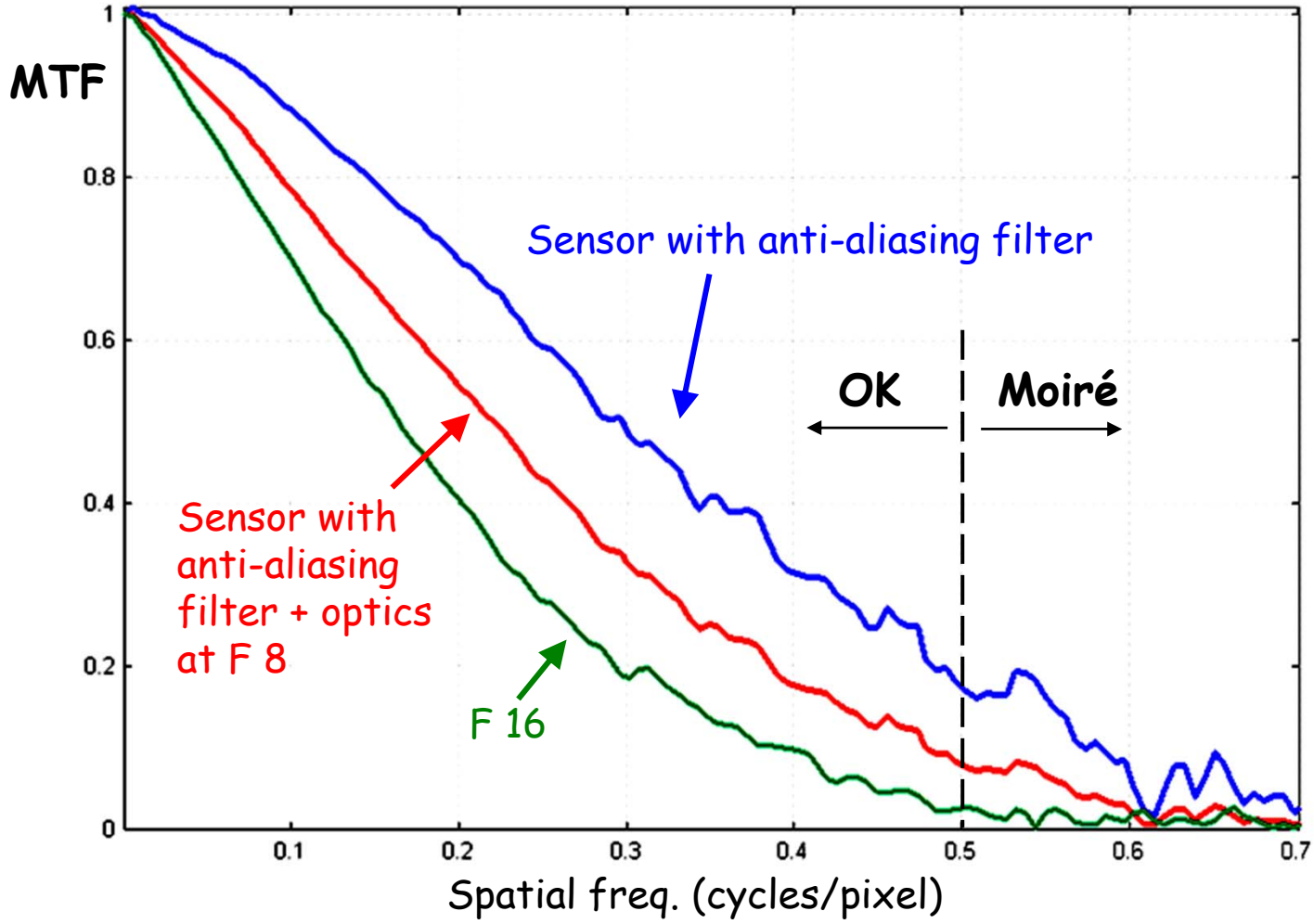
Real measurements



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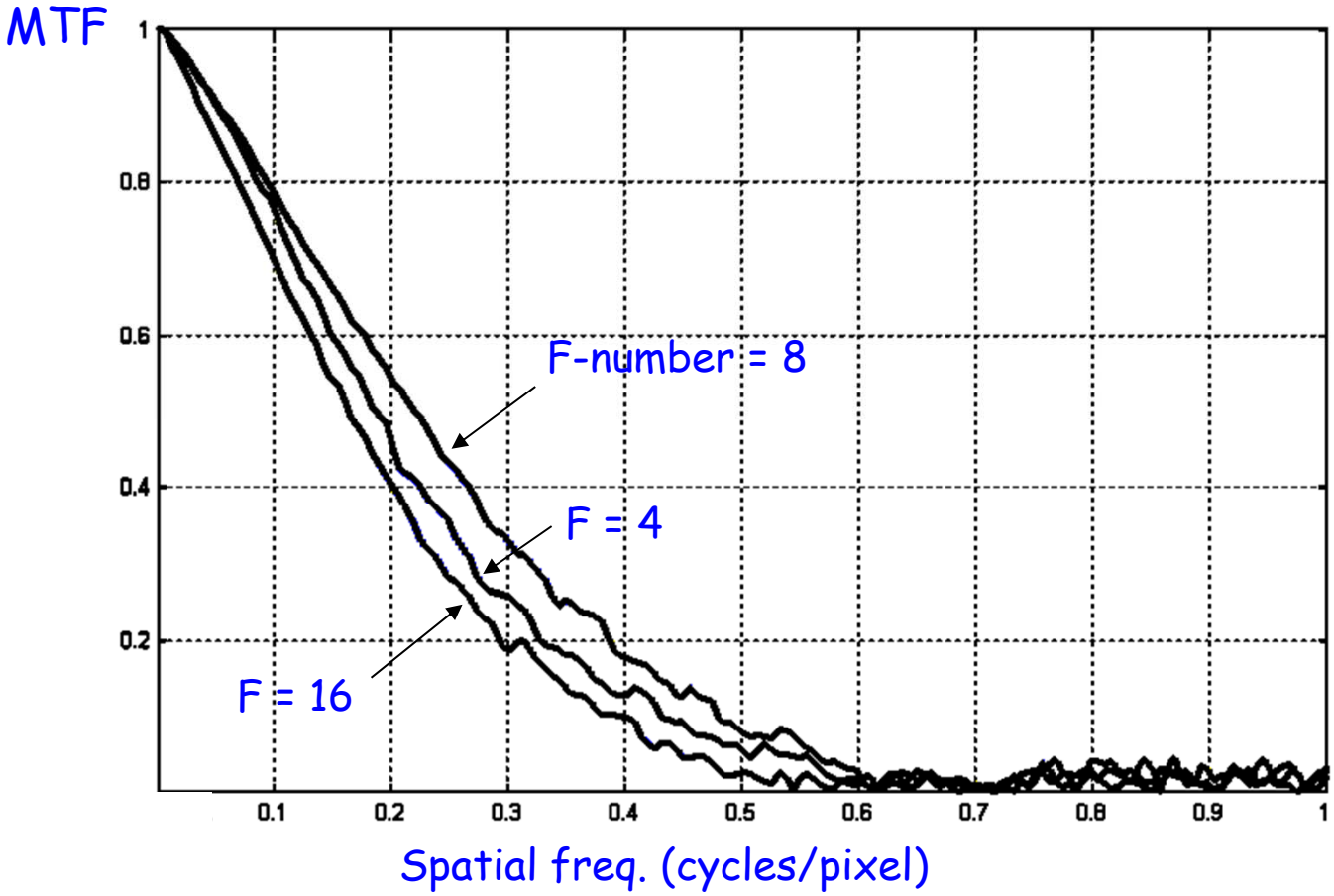
Influence of F-number



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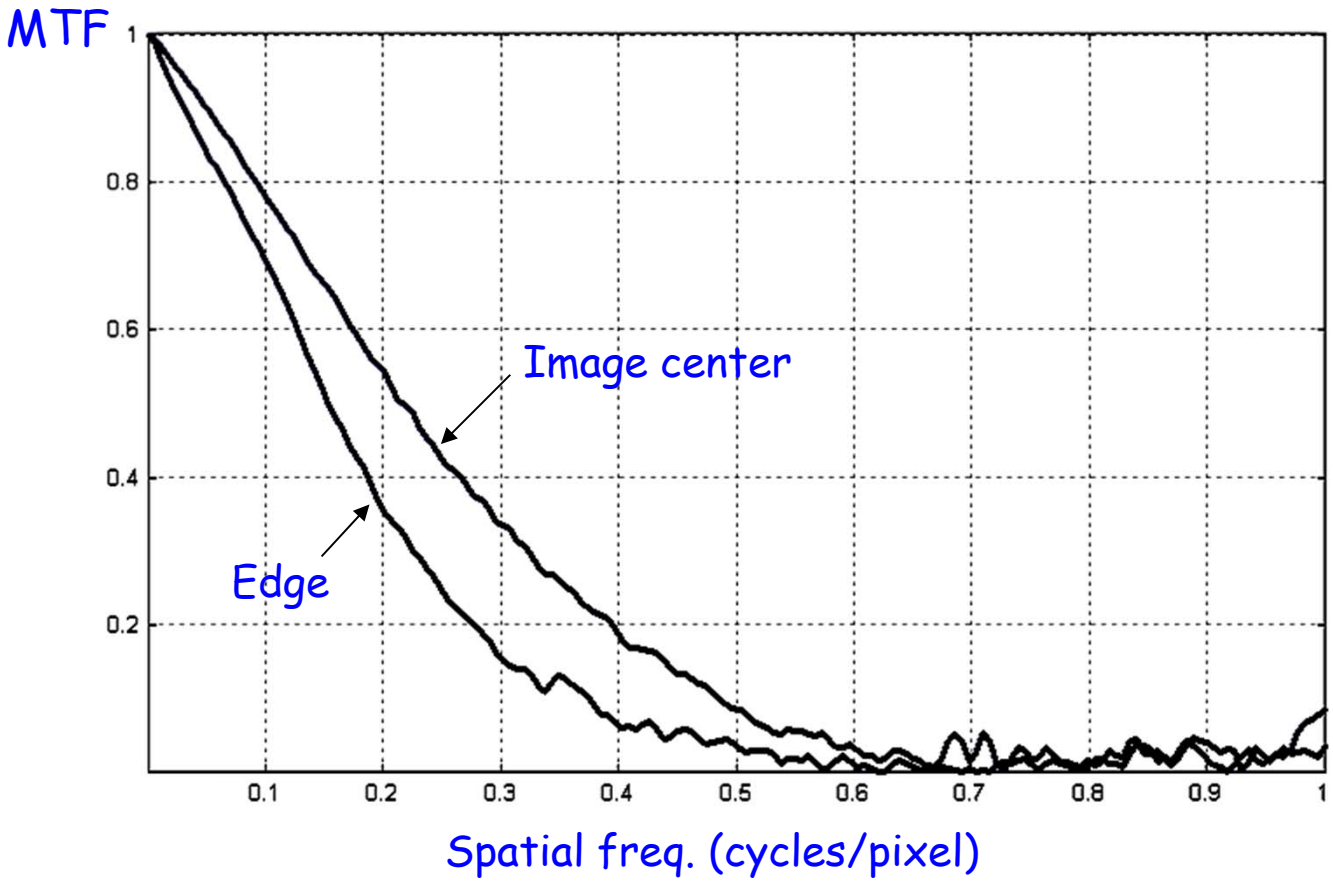
Center and edge performance



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It can be a bit tricky to compare MTF curves for sensors with different sizes and/or Mpixel numbers.

- If spatial frequency is given in mm^{-1}, sensor size must be taken into account
- If spatial frequency is given in cycles/pixel, Mpixel number must be taken into account

Solution: Use same technique as for resolution

Resolution given in "line pairs per picture height".

Numbers directly comparable regardsless of sensor size, megapixels etc.

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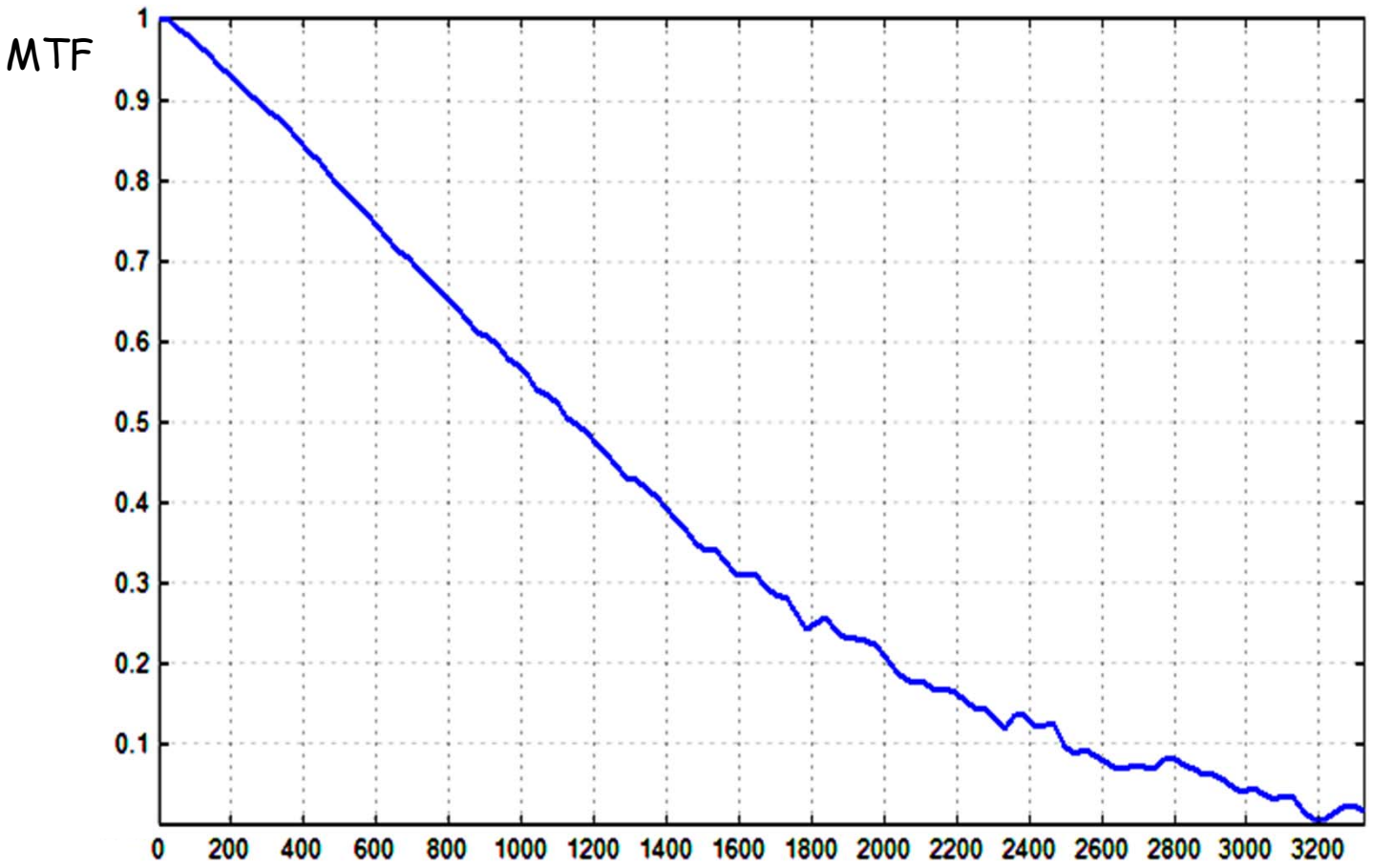
Give spatial frequency in units of line pairs per picture height



Line widths/picture height

(= 2 x line pairs/picture height)

Curves directly comparable regardsless of sensor size, megapixels etc.

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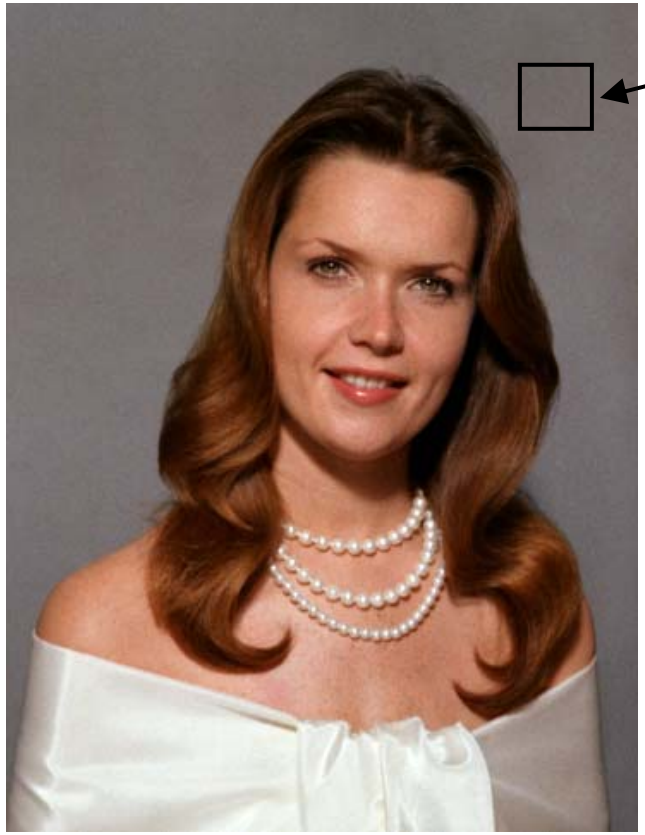
Photometric image quality

- Noise
- Dynamic range

Noise

Signal-to-noise ratio, SNR.



$$SNR = \frac{\text{Mean value}}{\text{Standard deviation}}$$

(Lab session 5)

Photo credit: Kodak

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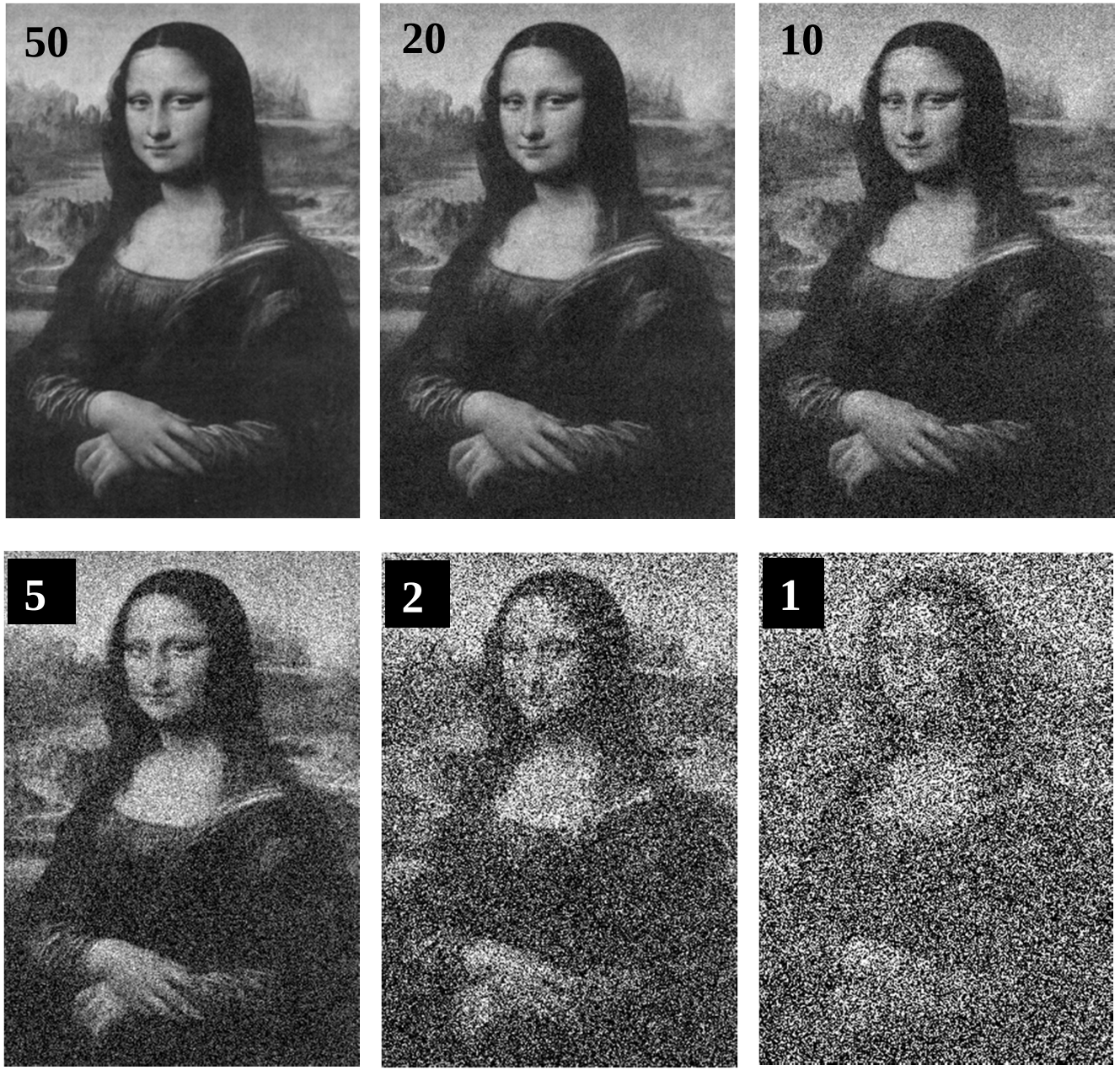
Images with different *SNR*



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Ultimate limit set by photon quantum noise to

$$SNR = \sqrt{N}$$

where N = number of detected photons per pixel.

Typically

$$N_{\max} \approx 40\ 000 \Rightarrow SNR_{\max} \approx 200$$

High ISO setting = Small $N_{\max}$ = Noisy image

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Dynamic range

The total span of light levels that can be rendered

From white sand on a beach

To a black cat in the shadow

$$DR = \frac{\text{Max. pixel value}}{\text{Stand. dev. in dark}}$$ = max. luminance ratio $\frac{L_{max}}{L_{min}}$ that can be rendered

Typically

$$DR \approx 3000$$

(for a good camera)

Compare human eye: $DR \approx 10\,000$

(HDR photography requires several exposures)

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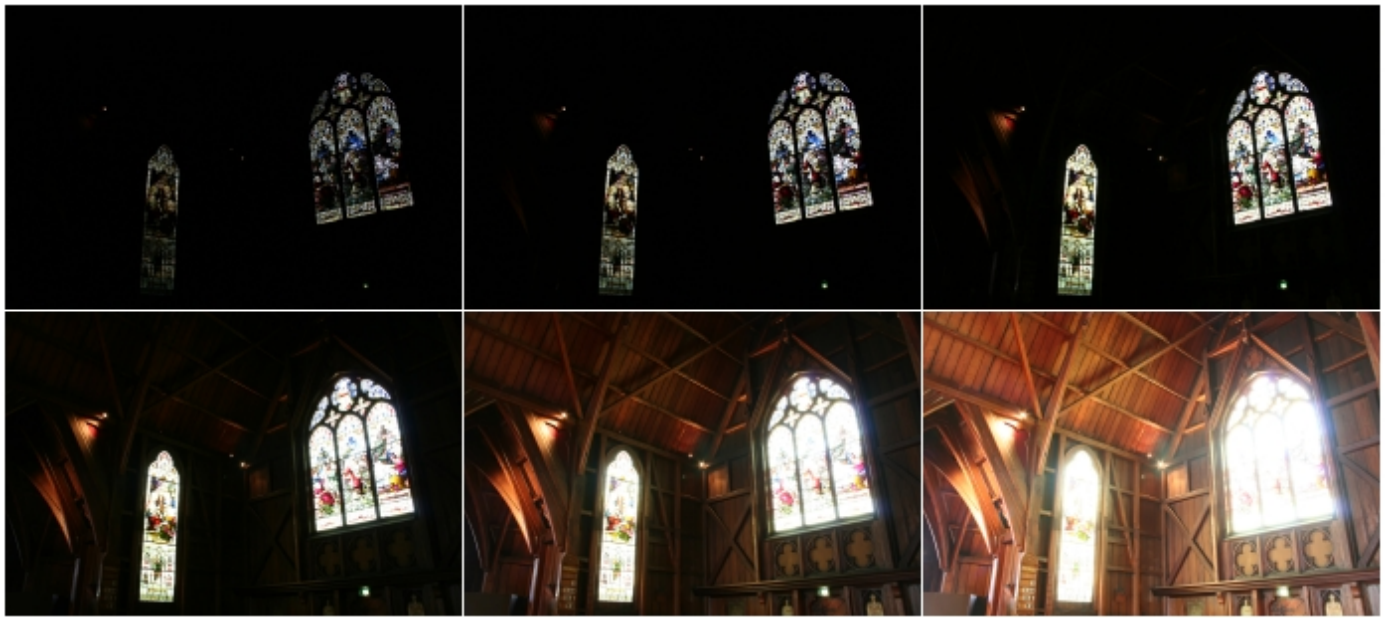
High dynamic range photography

(from Wikipedia, photo credit: Dean S. Pemberton)



6 expo-sures

Combined in one image