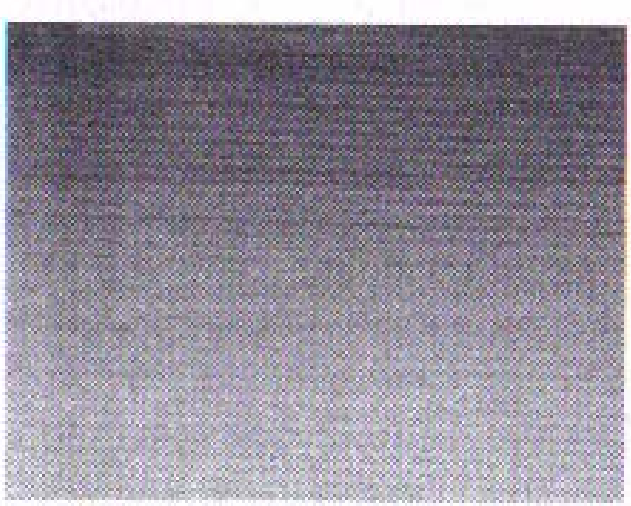
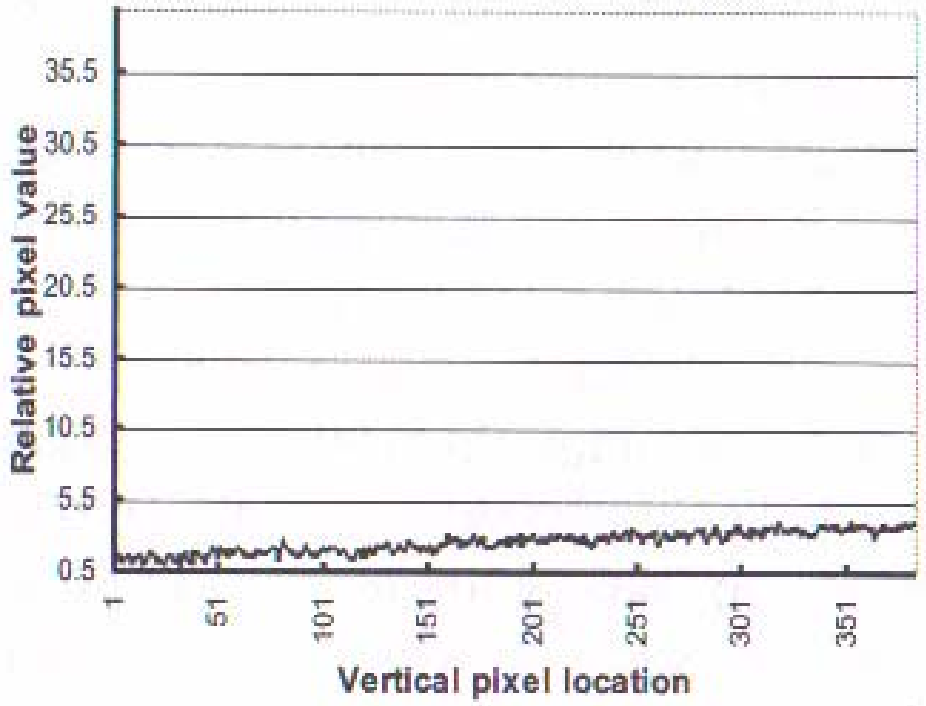
# *OFFSET AND NOISE COMPENSATION*

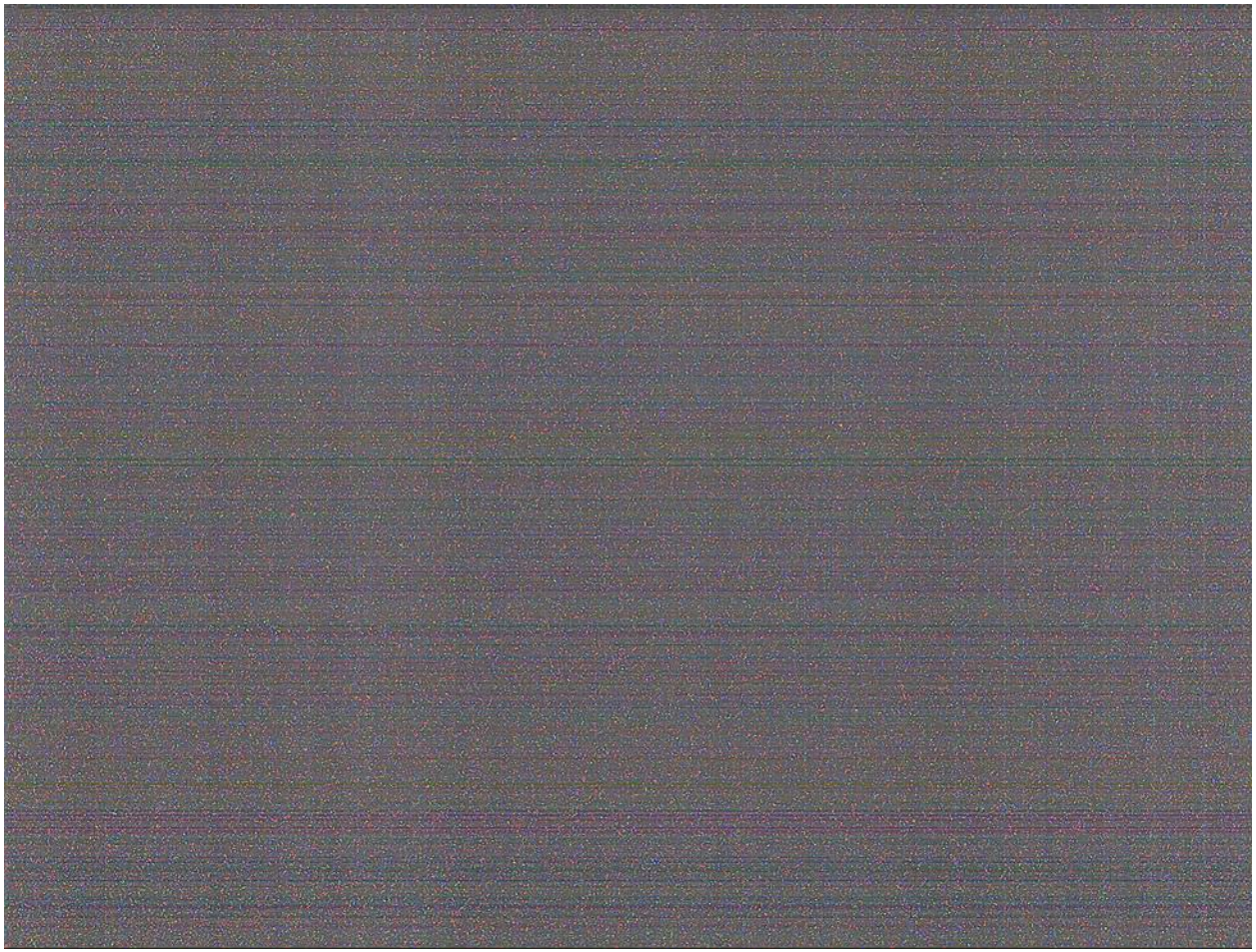
## Offset and fixed pattern noise reduction






Offset variation - “shading”

## Row Noise



# Offset compensation

### Global offset calibration

- Dark level is set by adjusting the offset at the ADC input, by means of a summing SC node or the ADC reference.
- Dark level is often set a few 10s LSBs above zero to utilize the ADC dynamic and to prevent clipping at the lower limit

### Compensation for variable offset

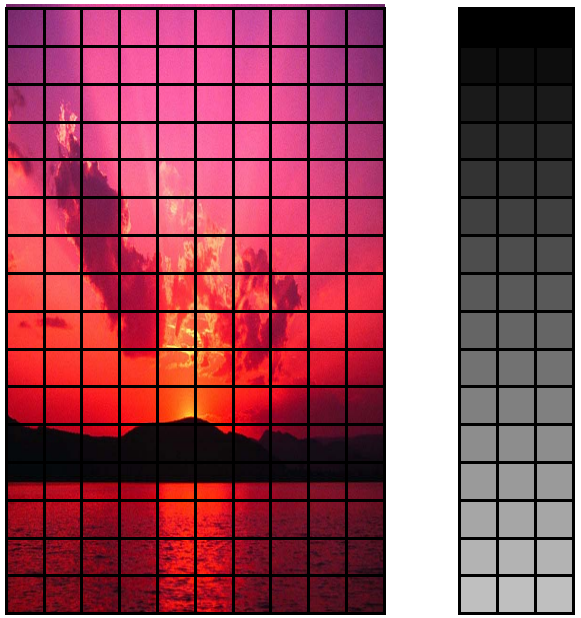
Usage of mechanical shutter and global reset release results in dark signal gradient due uneven integration of dark current with ERS (electronic rolling shutter).

With a global shutter sensor, integration of dark current on the storage node will cause a gradient in dark level.

Row wise compensation can be done by reading a set of dark (shielded) reference pixel of the same row and subtracting the average value form the signal in active array.

This method compensates for row noise (temporal and FPN) as well, provided the number of dark columns is sufficiently high. If not, the pixel wise noise in the dark columns would convert into row noise.

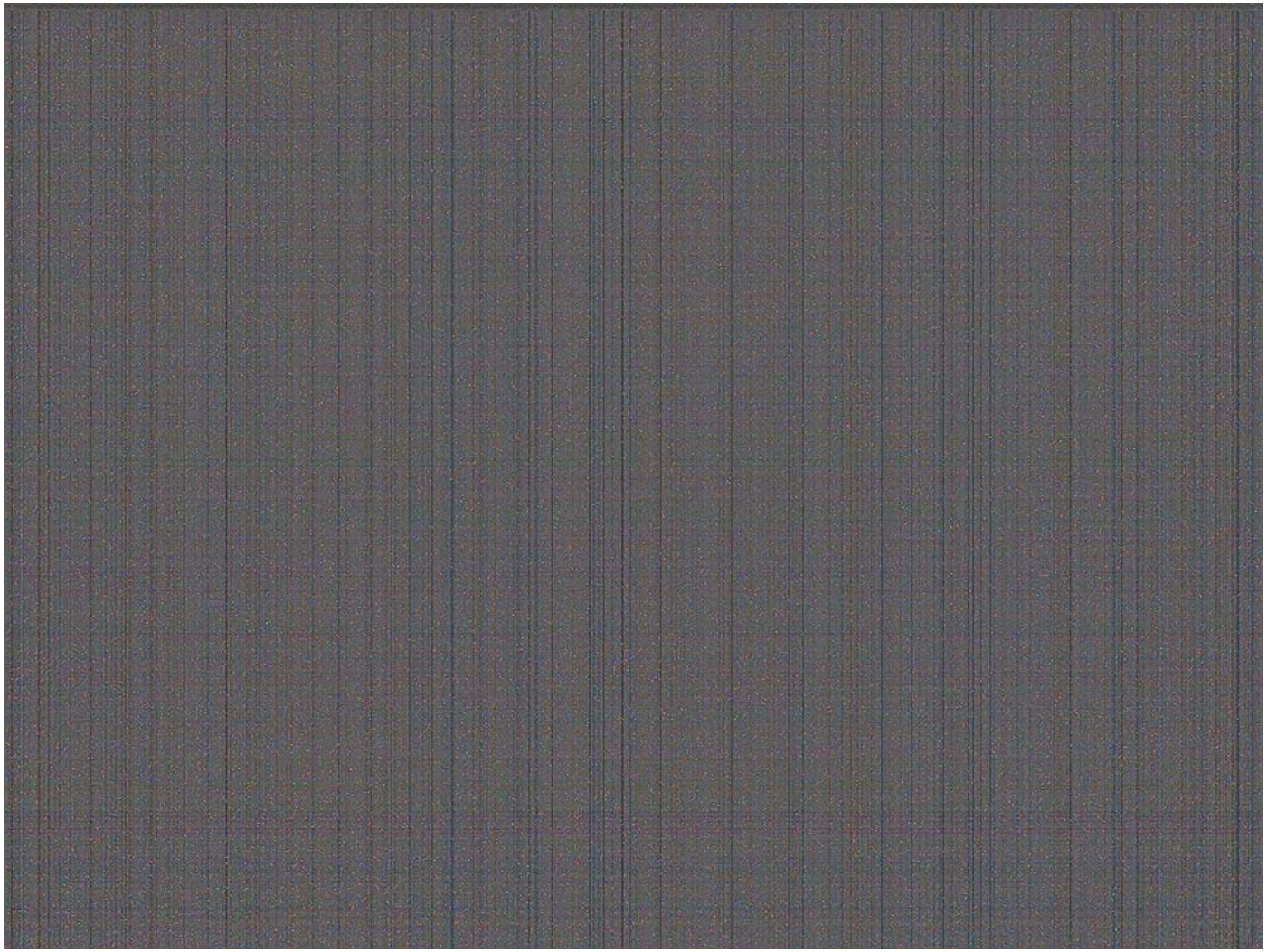
Compensation is usually done in the digital domain.



Active array

Dark reference columns

## Column Noise

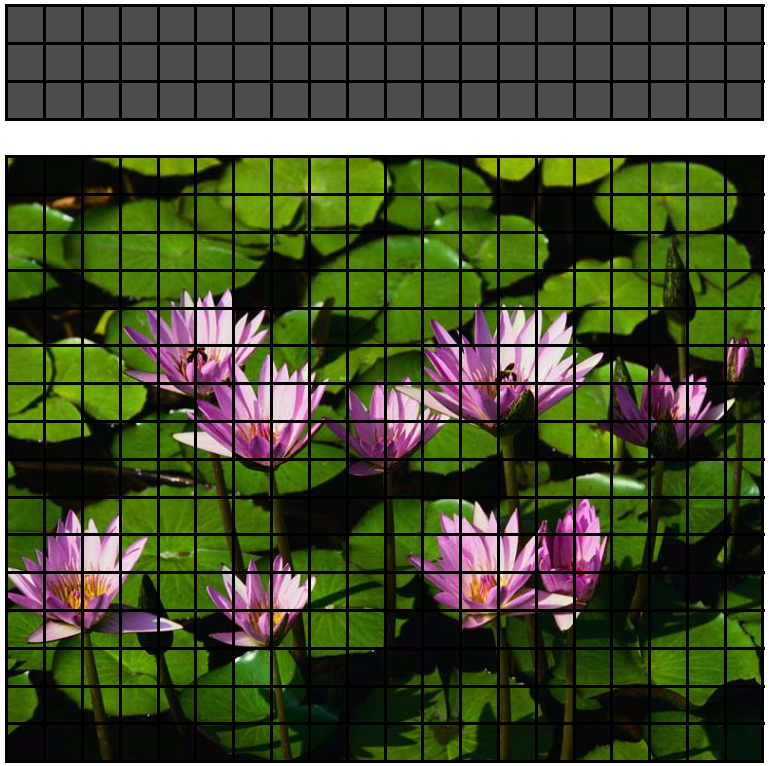


## Compensation of Column FPN.

Compensation values for each individual column is taken from the dark (shielded) reference rows.

Average over several row and even several frames, ensures that FPN only is compensated (temporal evens out).

Compensation is performed in the digital domain.



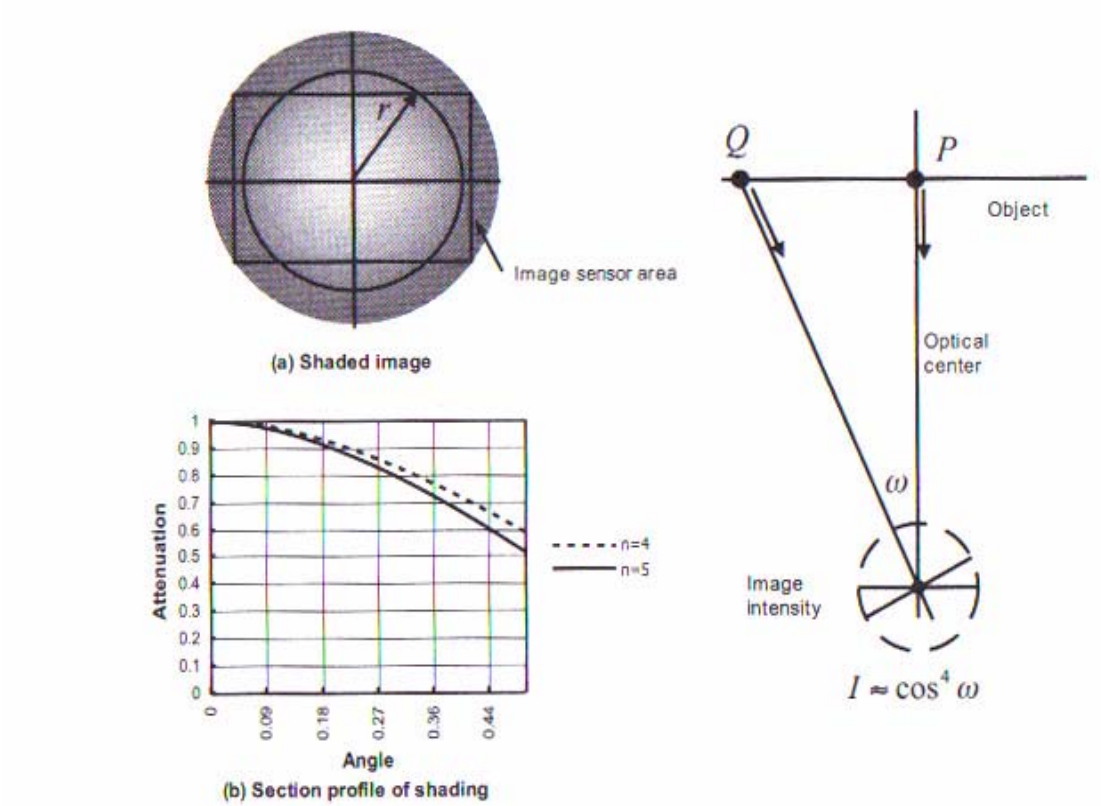
# Lens Shading - correction

Due to the properties of the optics, the light intensity is higher in the centre than at the periphery of the image.

This attenuation follows usually a $\cos^n\Theta$ shape where n is in the range 3-5.

$\Theta$ is the Chief Ray Angle, CRA.

Compensation by a gain function $1/\cos^n\Theta$
(for example by a look up table).



# *FILTER OPERATIONS*

Data filtering is necessary to improve the image quality.

- Low pass filtering prior to resampling
- Low pass filtering prior to interpolation
- Low pass filtering to remove overshoots.
- Colour interpolation (low pass filter function).

Low pass filtering blurs the image. Aperture correction,e.g. after colour interpolation is a high pass filter that boosts up edges making the image look sharper.

Example:

Assuming the colour interpolation (low pass filter) reduces the sharpness ($f_{org}$: original data). Blurring, or low pass filtering, is the convolution of the original image with a rectangular kernel h (the mask).

$$f_{blurr}(x, y) = h \otimes f_{org}(x, y)$$

The following filter increases the sharpness.

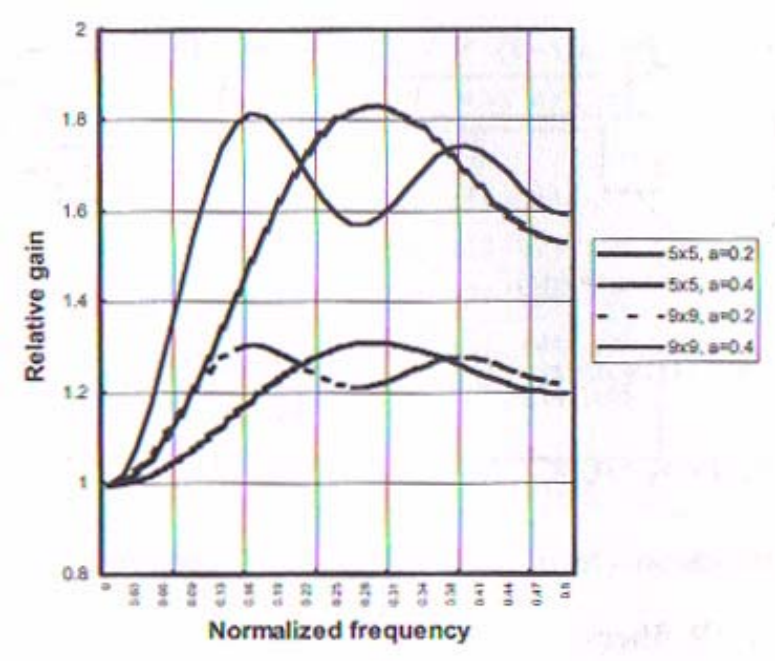
$$g(x, y) = \frac{[f_{org} - \alpha f_{blurr}]}{1 - \alpha}$$

$\alpha$ controls the the amplitude of the the high-frequency emphasis of the function g, and is set between 0 and 1.

Fourier transform (frequency response):

$$G(\omega_x, \omega_y) = \frac{F_{org} - \alpha HF_{org}}{1 - \alpha} = \frac{1 - \alpha H}{1 - \alpha} F_{org}$$

Where $HF_{org} = F[h \otimes f_{org}(x, y)]$

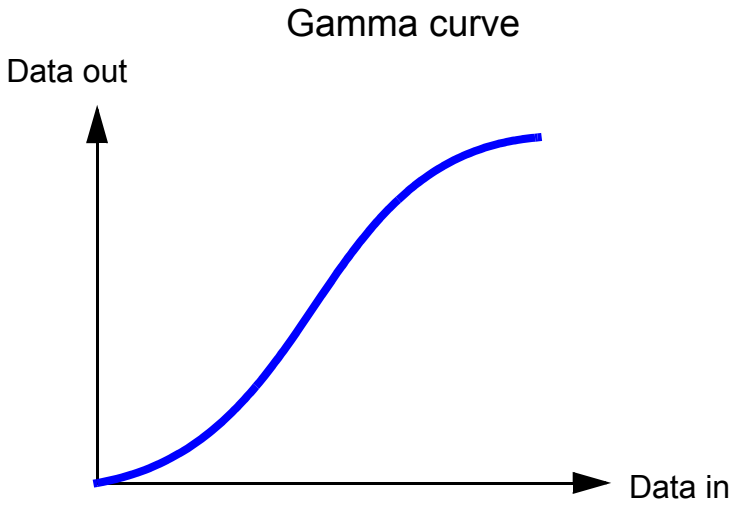


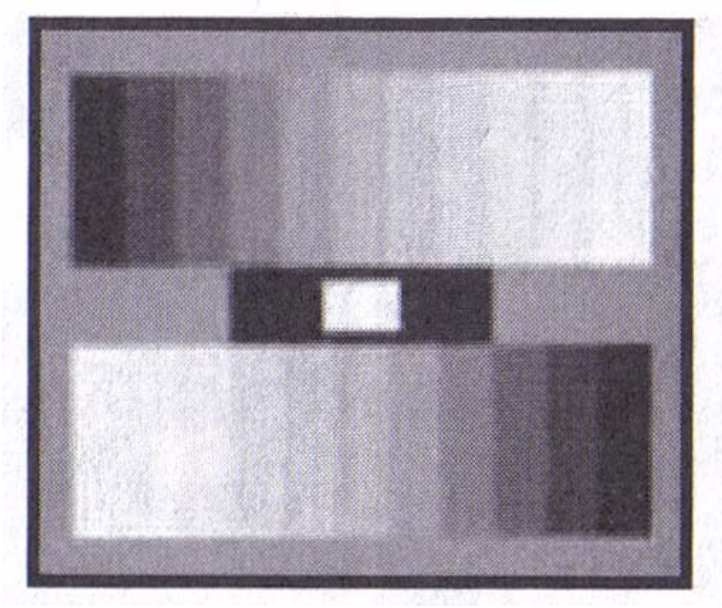

h: 5x5 and 9x9.

$\alpha$: 0.2 and 0.5

# Gamma correction

- Aligns the gradation of the recording unit and the displaying unit.
  Linear response requires that the illuminance from the display or paper is proportional to the illuminance from the object being recorded.
- Gradation curve: $y = k\, x^{\gamma}$
- Compressing the response in the bright areas and dark areas, means that the dynamic range of the reproduced image is less than the dynamic range of the scene.
- For example: CRT has a standard $\gamma = 0.45$. That is compensated in the TV set.
- Digital cameras have no standard, important parameter in the data sheet.
- Measured by the response form a chart of defined reflactance

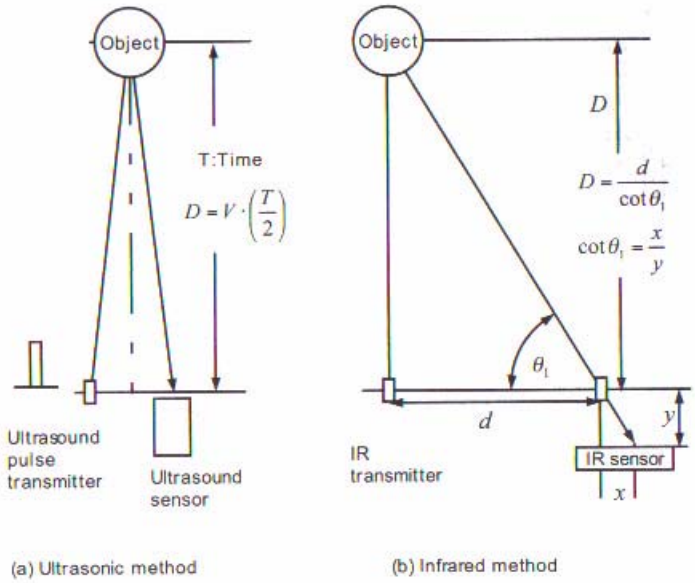


# Auto Focus

Traditionally

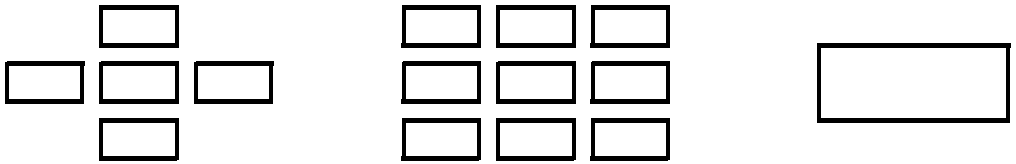
Auto focus has been dependent on additional sensors and sources. (ultra sound or infrared light).



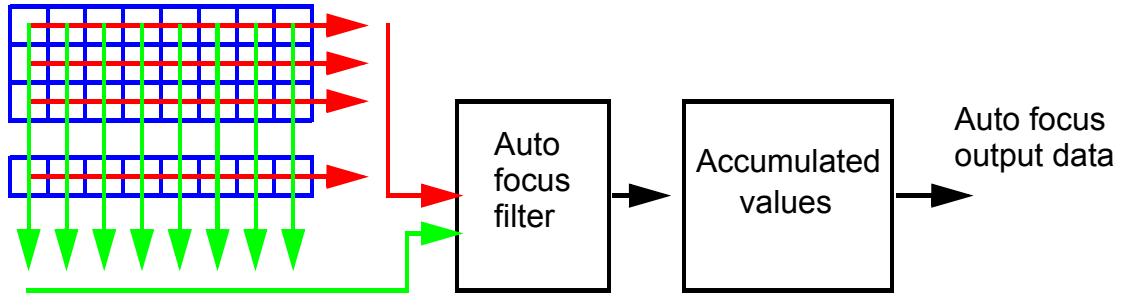
## Digital Sensors

The image data are utilized to adjust the focus. One method is based on the spatial high frequency content is highest when the image is focused (at the sharpest). The data are scanned and weighted with a band pass filter.

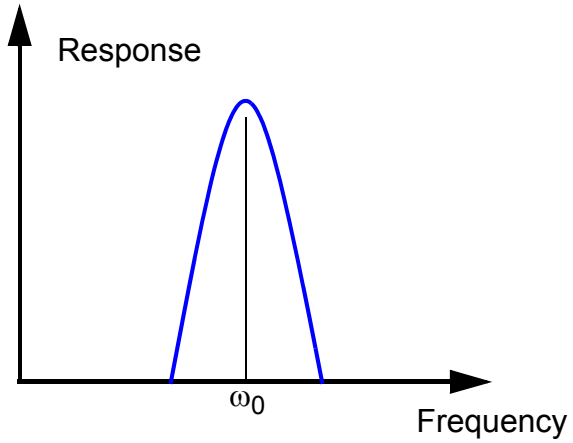
The methods gives the freedom to use a complex set of windows and strategies for auto focus.

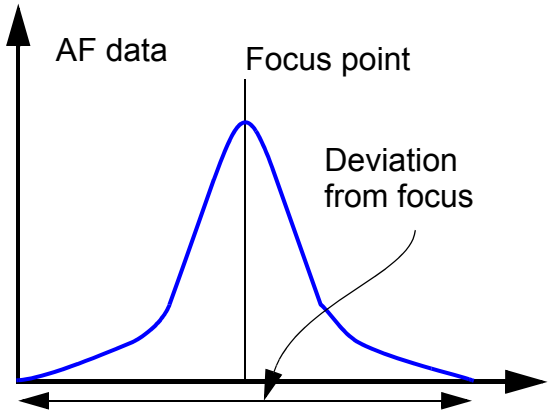


AF-windows




Row/column scanning, filtering and accumulation



## Electronic (digital) zoom

Select a subset of the pixels, increase the separation and insert new pixel values in positions between the original positions by interpolation.

The interpolated values are found by low pass filtering.

Generally:

$$p(x) = \sum_i f(x - x_i) \cdot g(x_i)$$

Closest neighbour, i.e. zero order:

$$f(x) = 1 \qquad 0 \le |x| < 0.5$$

$$f(x) = 0 \qquad 0.5 \le |x|$$

Linear interpolation, i.e 1st order:

$$f(x) = 1 - x \qquad 0 \le |x| < 1$$

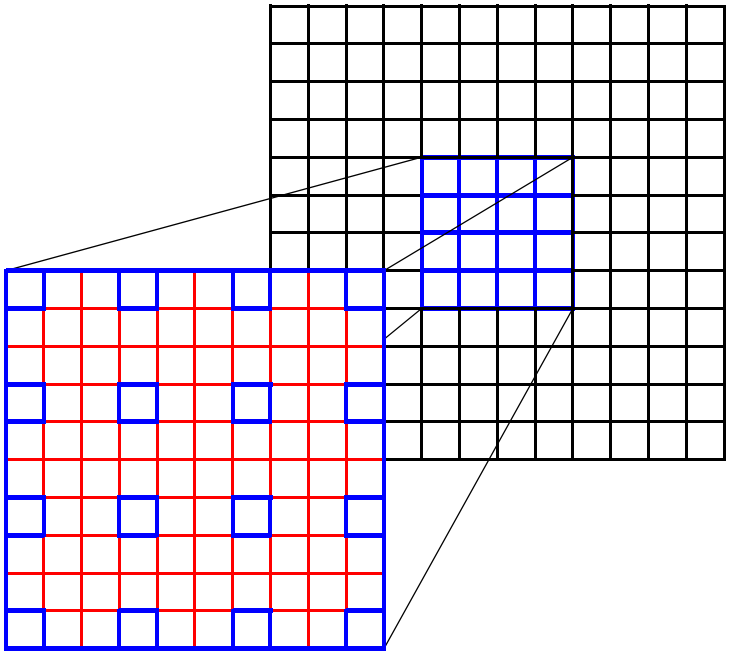
$$f(x) = 0 \qquad 1 \le |x|$$

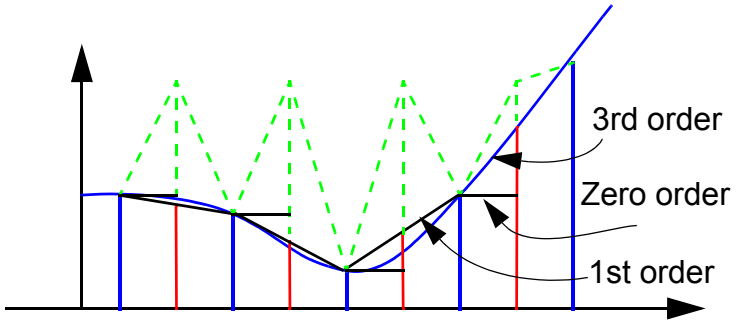
Cubical interpolation, i.e. 3rd order

$$f(x) = (1-x)(1+x-x^2) = 1 - 2x^2 + x^3 \qquad 0 \le |x| < 1$$

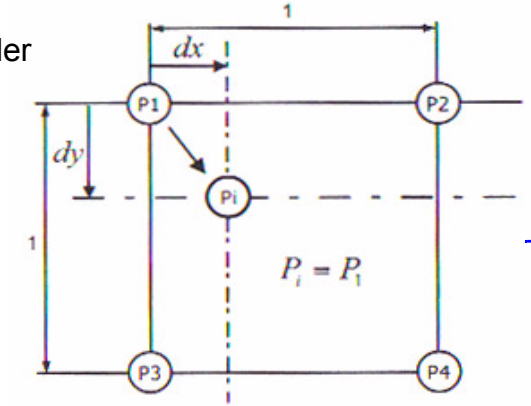
$$f(x) = (1-x)(2-x^2) = 2 - 2x - x^2 + x^3 \qquad 1 \le |x| < 2$$

$$f(x) = 0 \qquad 2 \le |x|$$

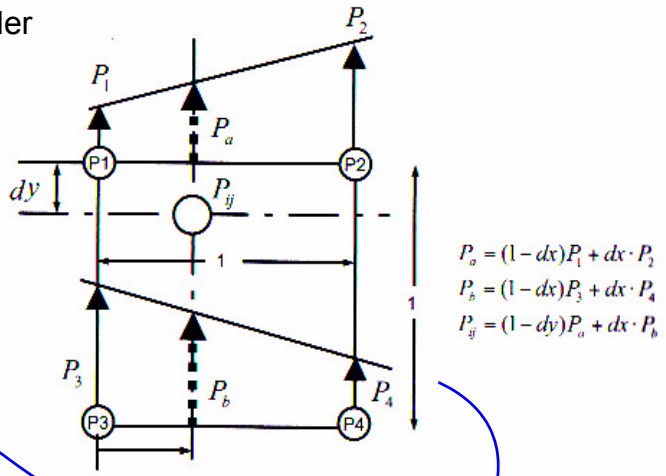




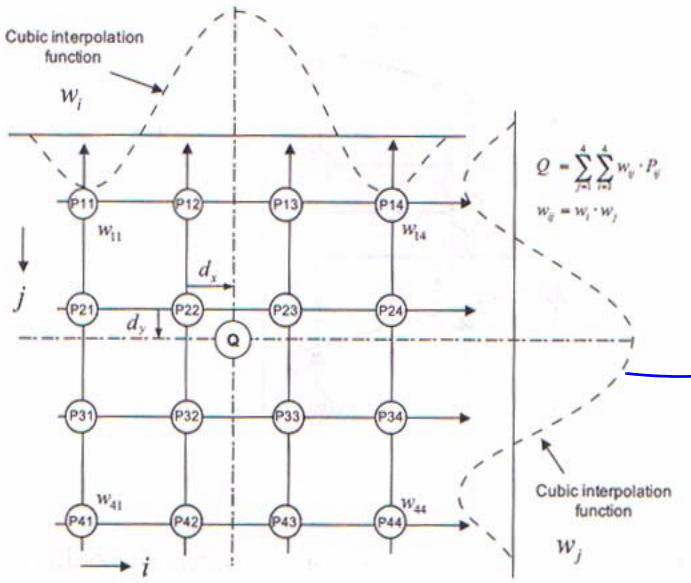
Zero order

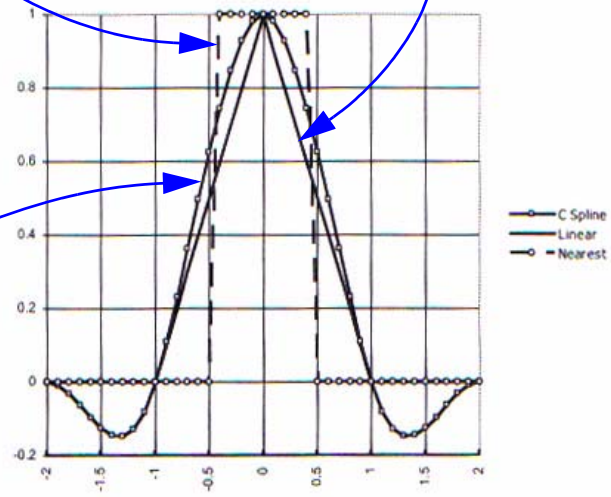



1st order




3rd order



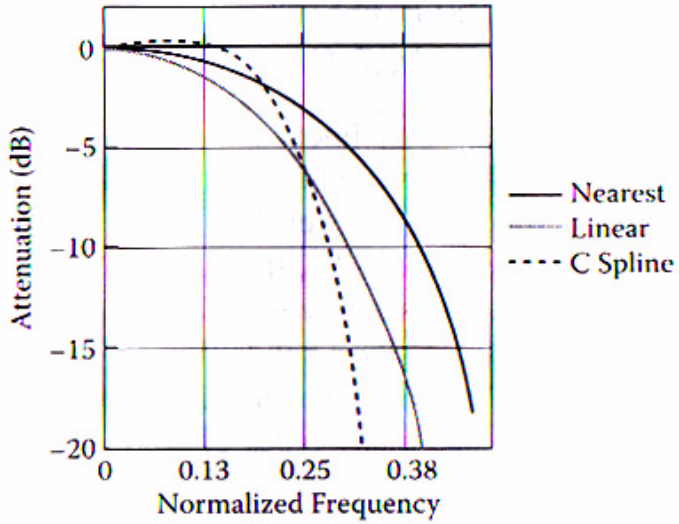



**TABLE 8.4**
**Number of Multiply/Addition of Interpolation Functions**

| Interpolation function | Order | Multiply/add (one dimension) | Multiply/add (two dimensions) |
|---|---|---|---|
| Nearest neighbor | 0 | 0 | 0 |
| Linear | 1 | 2 | 4 |
| Cubic spline | 3 | 4 | 16 |

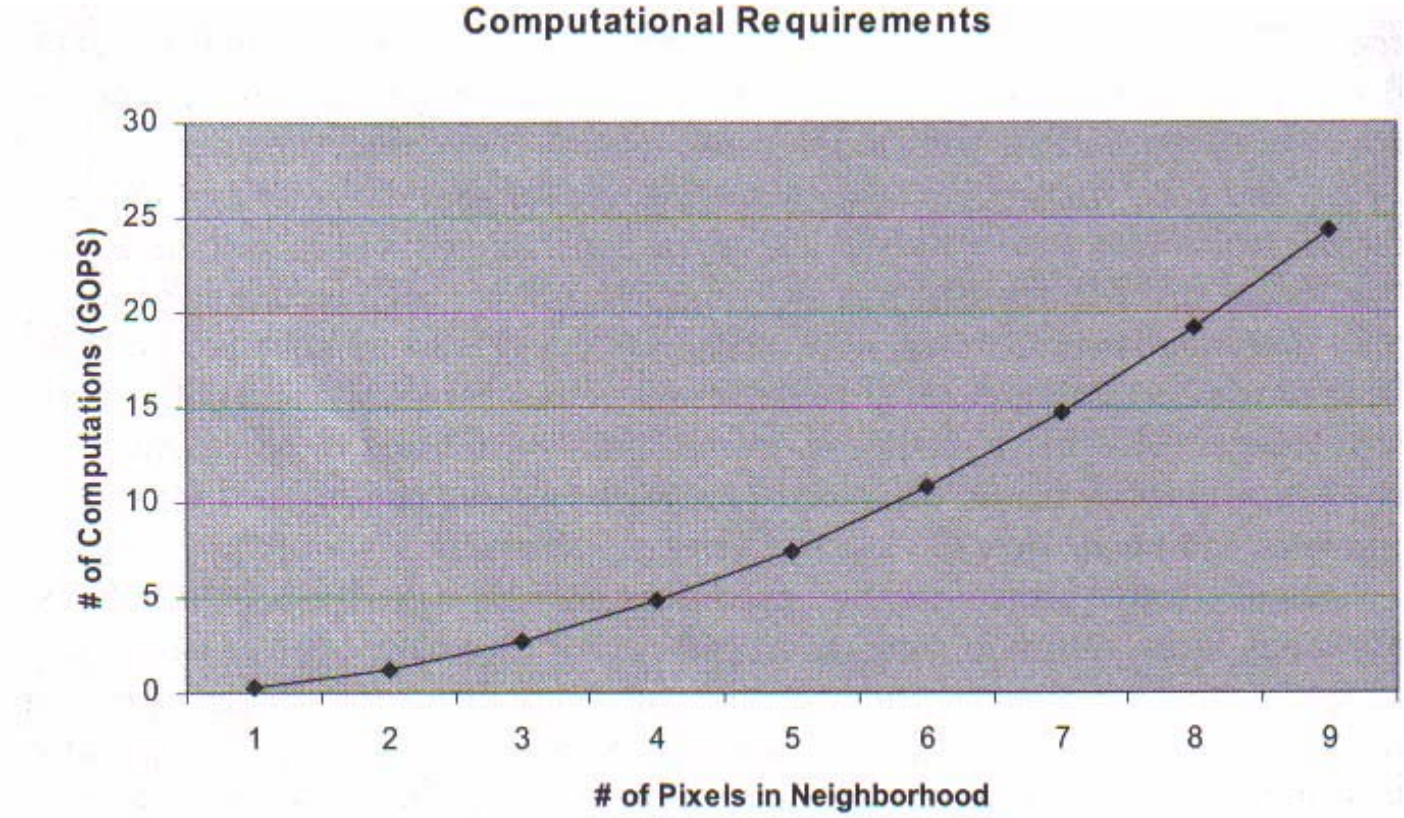



**FIGURE 9.4** Computational requirements (in case of 3 Mpixels, 10 fps).

# Data Compression

**Lossless compression**

- Removes redundant information - Changes the data format
- Can be reversed - Recreate data identical with the original data.
- GIF is limited to 256 colours - too little for photography.
- PNG gives large files.

**Lossy compression**

- Removes information - Cannot recreate the original image.
- Visible effects is dependent on the degree of compression.
- Common file format: JPEG (Joint Photographic Experts Group).
  - Specifies the transformation of image data to streaming bytes.
  - JFIF (JPEG File Interchange Format) minimum version of JPEG.
  - Other JPEG based file formats: JNG

**Other File formats:**

TIFF (Tagged Image FIle Format) can be compressed or uncompressed. Flexible format which is used as container for a JPEG compressed image.

*Ref.: Wikipedia*

# JPEG encoding

- RBG -> $YC_bC_r$
- Subsampling of $C_b$ and $C_r$
  - Reduces the data of the colour information.
    The eye has lowers resolution for chrominans than for luminance.
- Splitting the array into sub arrays 8x8
- Performing Discrete Cosinus Transform (DCT)
- Reduces the quantization resolution in high frequency components
  - Removes frequency components of small values; are set to zero.
- Entropy coding
  - The array elements are scanned in a “zigzag” order.
  - Run-length encoding
  - Huffmann coding (minimum redundant data)

*ref.: Wikipedia*

## Example:

**Removed frequency components with small amplitude**

**JPEG: 517kB**
**BMP: 2.06 MB**

**JPEG: 77kB**

# References:

*Nakamura*

*Image Sensors and Signal Processing for Digital Cameras*
*Junichi Nakamura (editor)*
*CRC - Taylor & Francis*

*Wikipedia*

*http://en.wikipedia.org/wiki/Comparison_of_graphics_file_formats*
*http://en.wikipedia.org/wiki/Jpeg#Encoding*