CHARACTERIZATION

Test systems

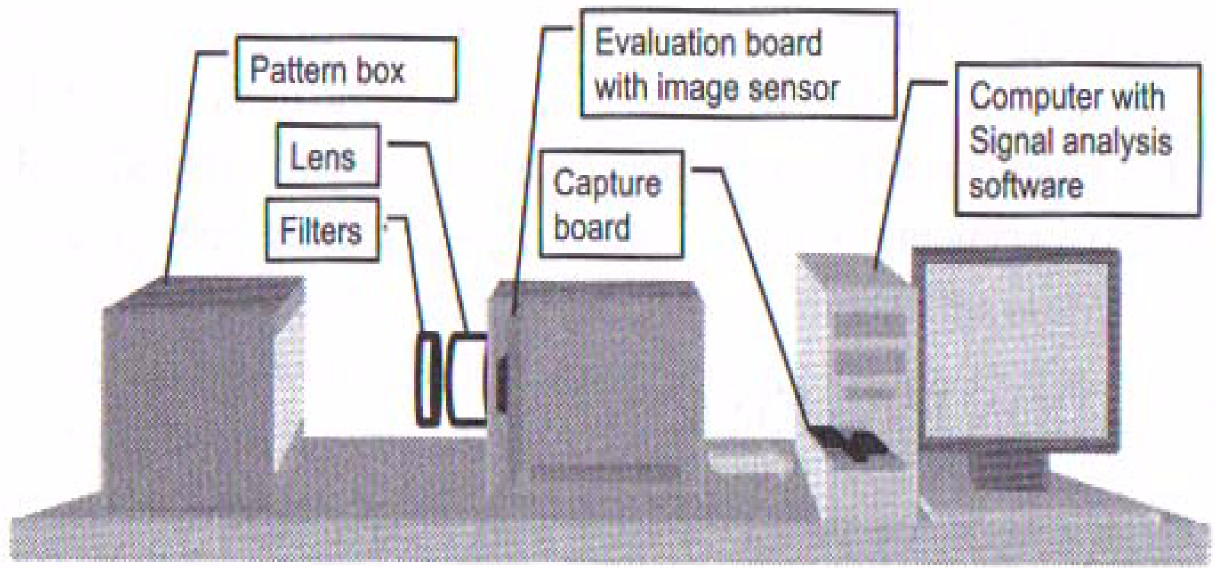
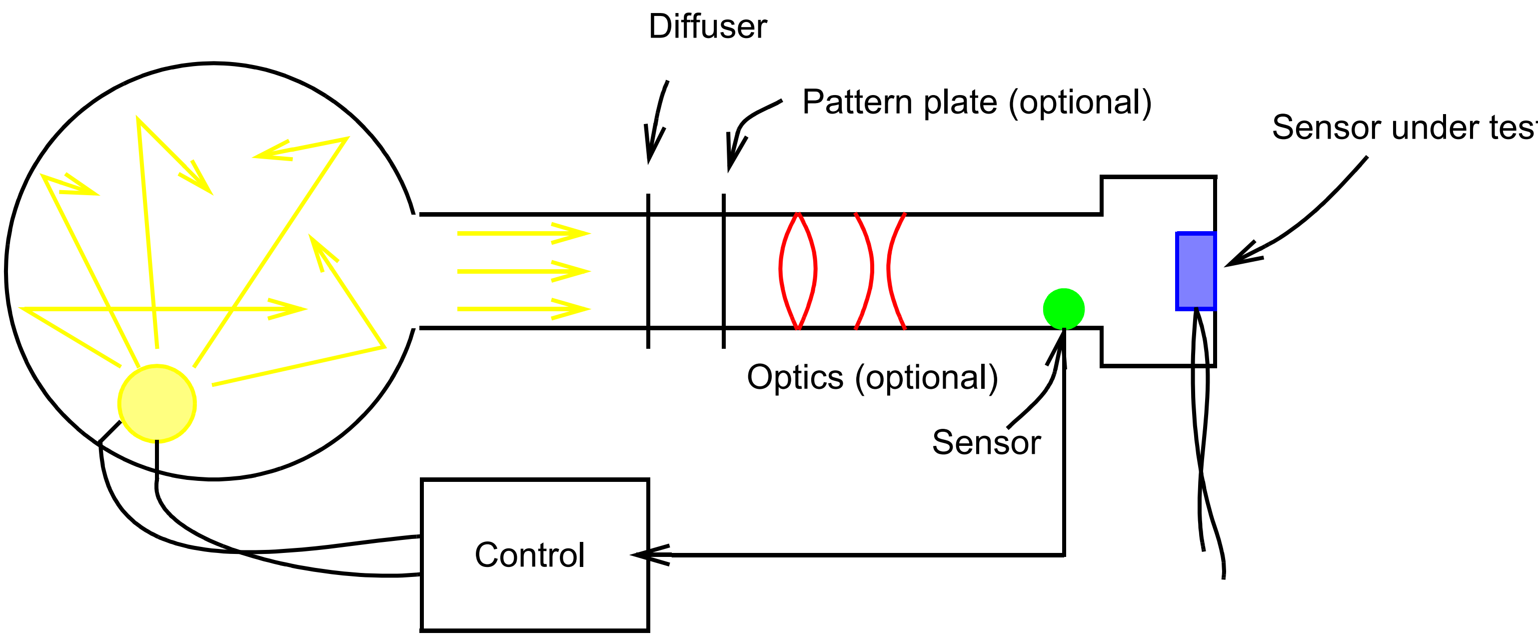
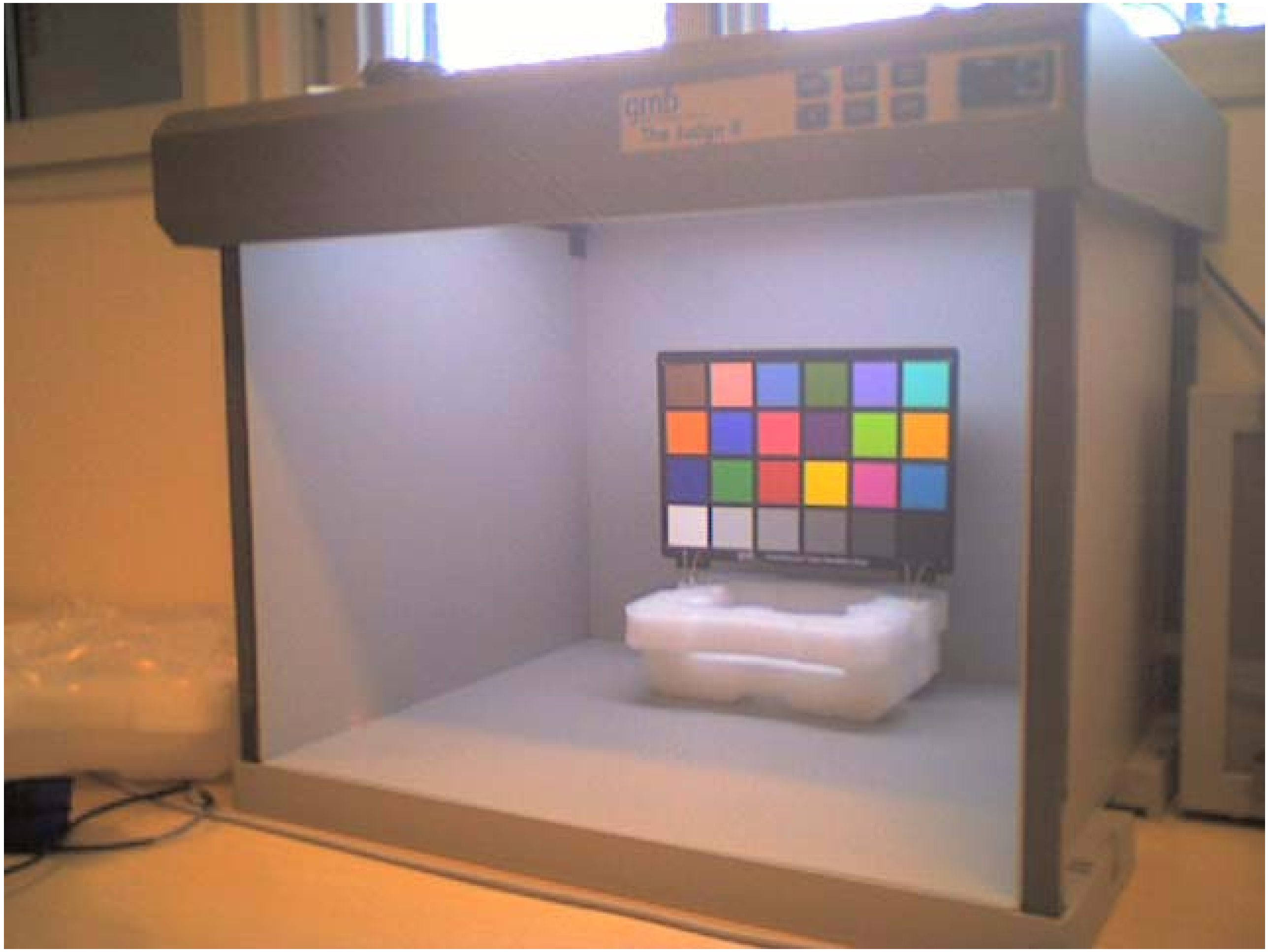


FIGURE 6.2 A basic configuration of the image sensor evaluation environment.

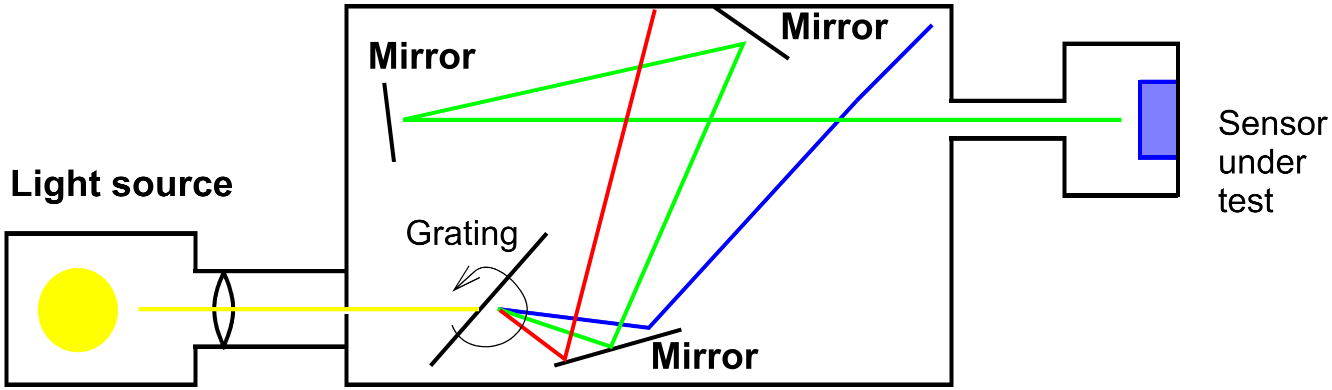
Optoliner


Diffuser
Pattern plate (optional)
Sensor under test
Optics (optional)
Sensor
Control

Light Box



Monochromator

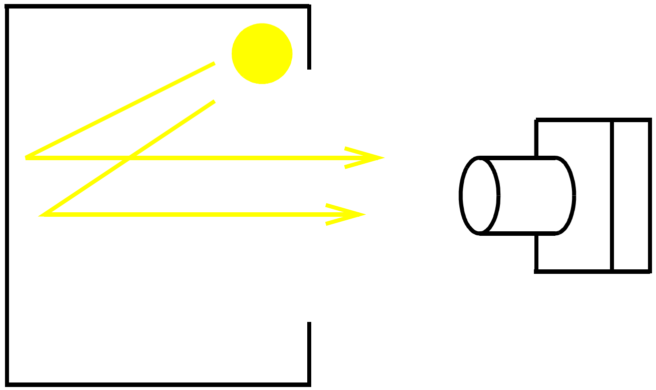


The angle of the grating determine the wave length that enters the sensor

Measurement of intensity

$$E_p = \frac{E_o R T_L}{4F^2(m+1)}$$

Where
E_o is the source intensity,
R is the box reflectance,
T_L is the optic's transmission factor, and
F is the aperture.



Alternative: Use of optoliner without optics (no attenuation)

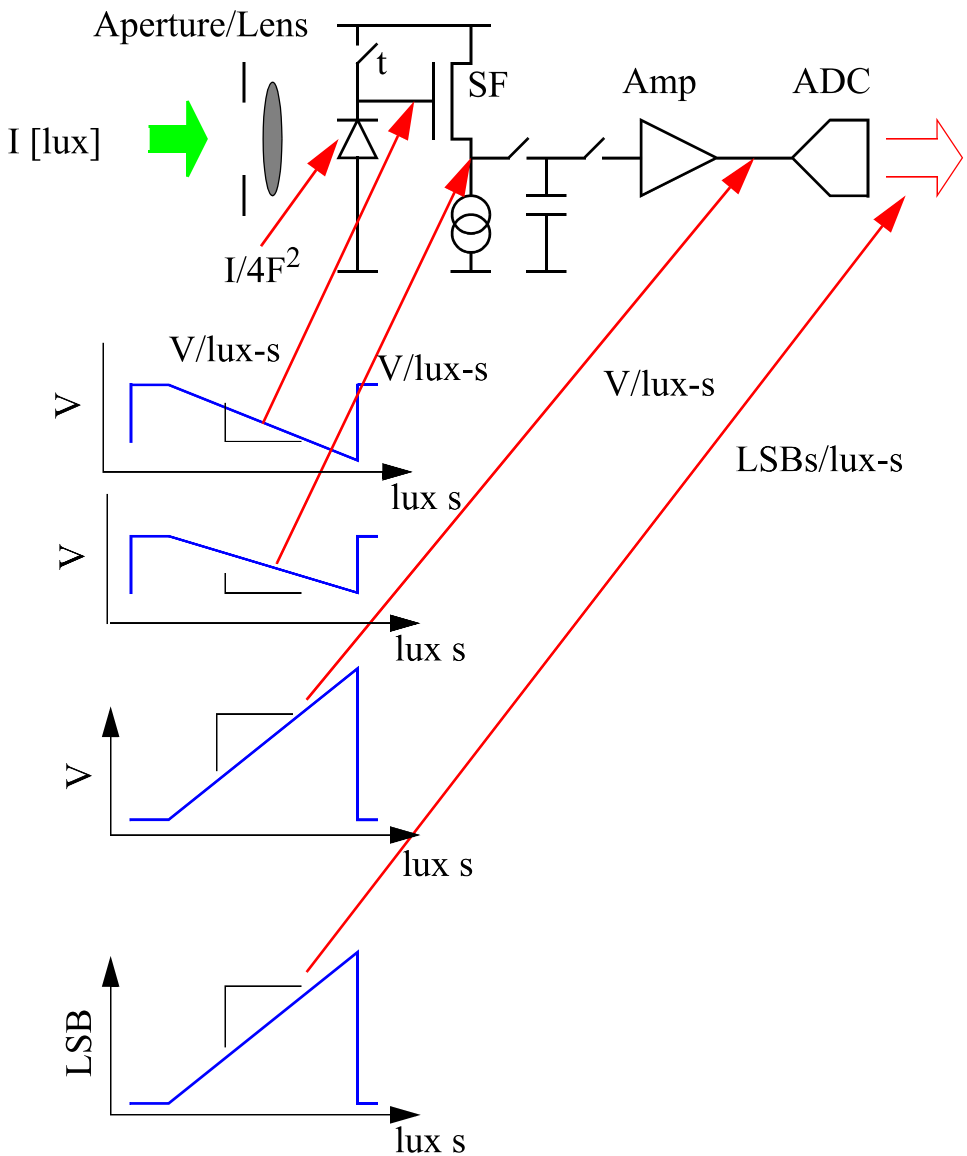
Responsivity

The gradient of the output signal as a function of the light intensity.
Measured by output signal as a function of the intensity and the integration time.

Represented in volt per lux-second or in number of least significant bits per lux-second.

Responsivity: V/lux-s, LSB/lux-s

Incoming light is reduced due to the aperture proportion to $1/4F^2$,
converted to charge in the photo diode,
converted to voltage according to the conversion gain, (capacity of the diode, $1/C_{pd}$).
The voltage is reduced in SF and gained up in the amplifier.
The voltage is converted to LSBs in the ADC.

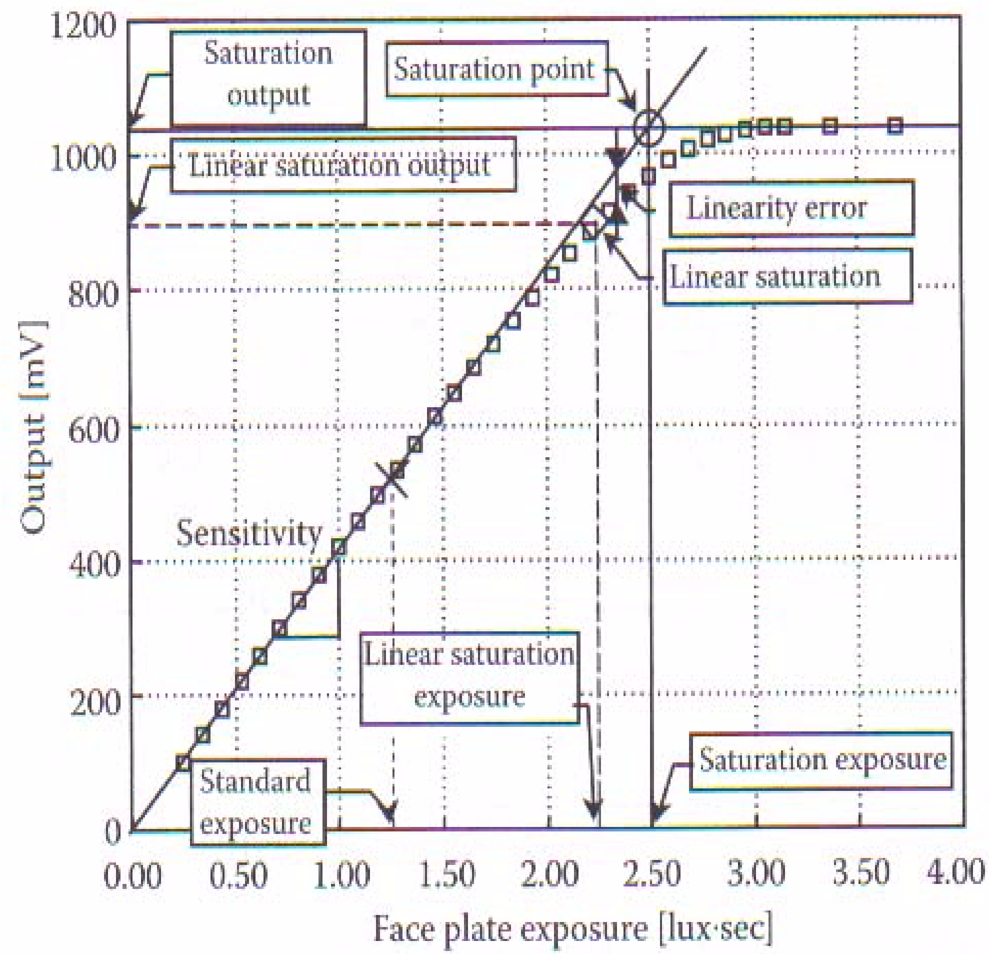


Measurement of Responsivity

Sweep integration time

- For each integration time, one image and one dark frame, with same integration time, are stored.
- The dark frame is subtracted from the image.
- The mean value is calculated for section if the image (centre) for all colour plans (4).
- Adapt a straight line output value as a function of the exposure.

The interesting measure for the responsivity, is V/lux-s after gain or LSBs/lux-s.



Spectral response

Use of monochromator

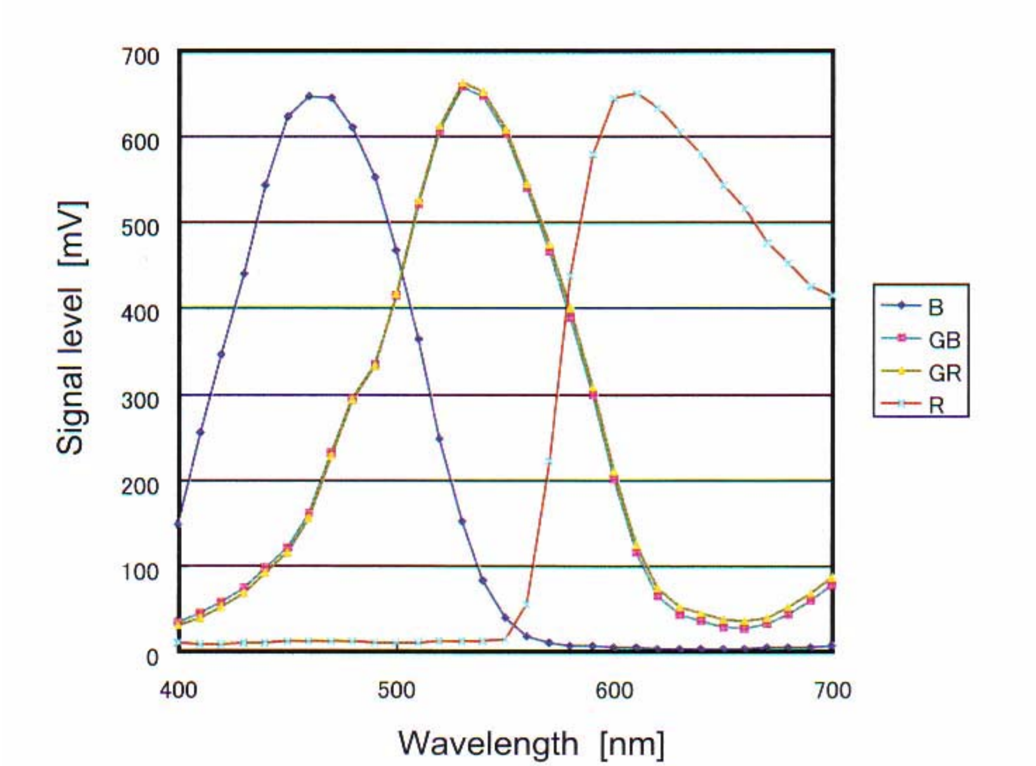
Linear part of the response curve

Collimated light

Subtraction of dark frames to eliminate the dark current.

Constant light, or constant output signal and feedback to the light source (control loop).

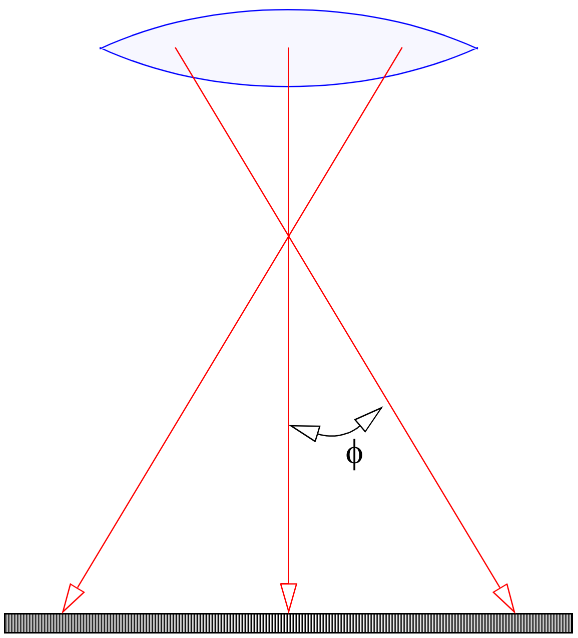
All colour plans

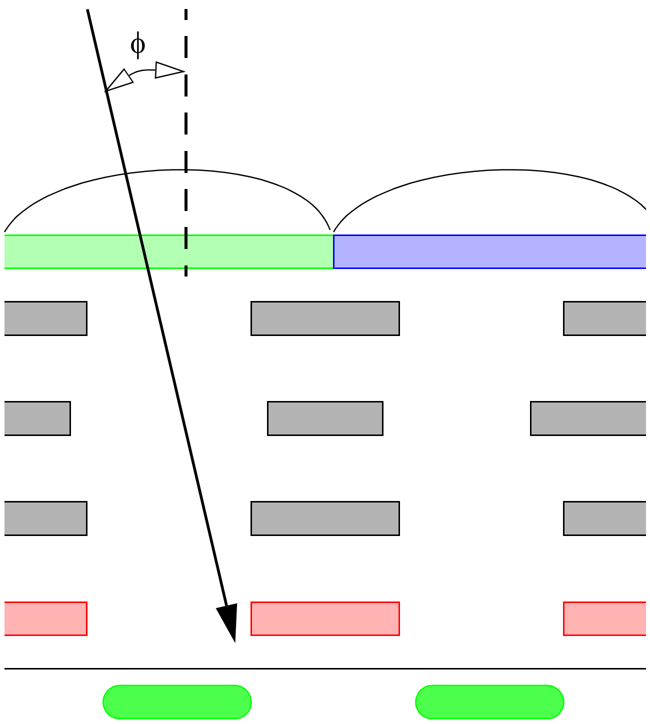


Uniformity

Light angle

CRA (Chief Ray Angle) is determined by the optics and the distance between the optics and the sensor surface. The responsivity depends on how the light is hitting the pixel. The result is shading. I





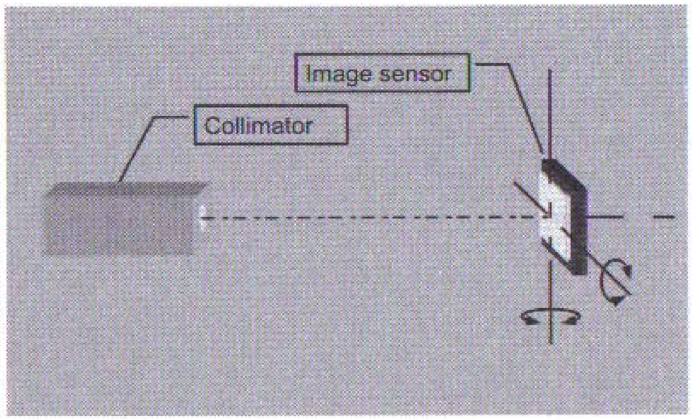
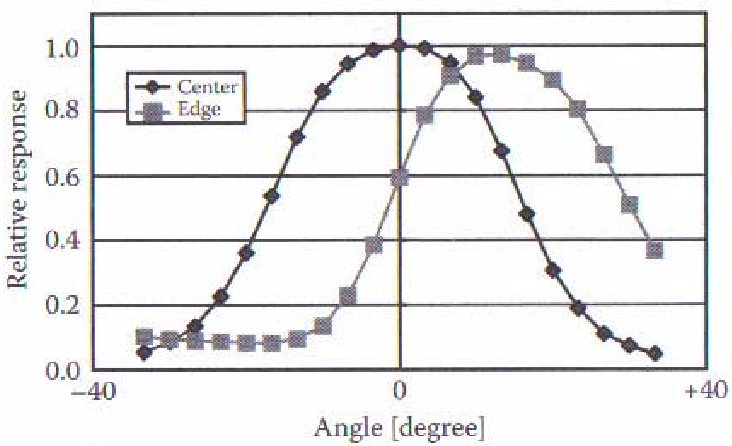
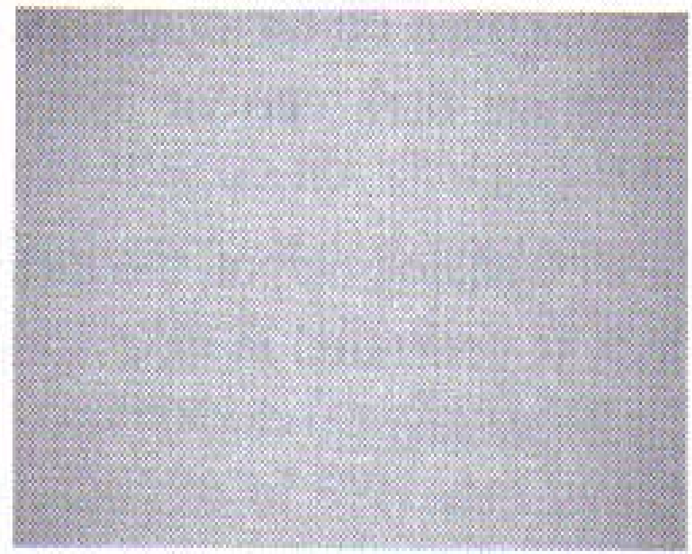


Image sensor
Collimator


1.0
0.8
0.6
0.4
0.2
0.0
Relative response
Center
Edge
−40
0
+40
Angle [degree]



Dark Signal

Integrated dark current, due to thermal generated charge carriers, results in dark signal.

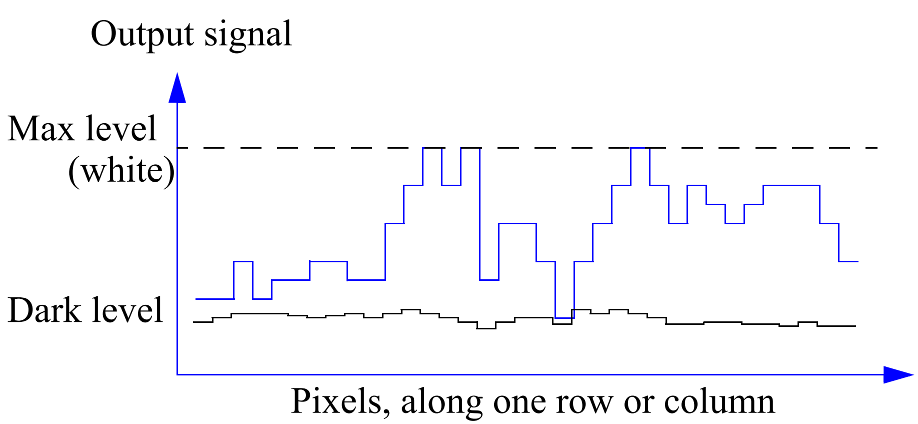
At a given temperature, the dark signal appears as a pedestal, a dark level, above the zero level. Thus “black” is not totally black.

Black levels are temperature dependent and, typically the dark current doubles per 6-8 °C.

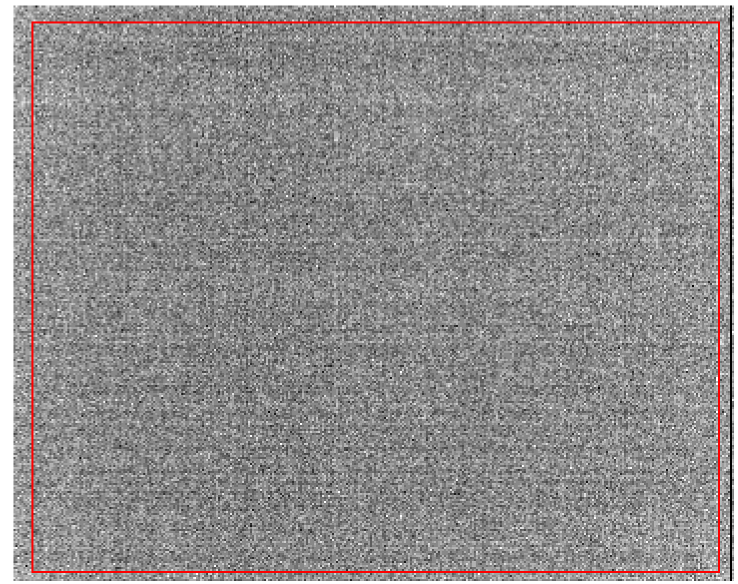
Dark current vary form pixel to pixel. The result is a non-uniform dark level.

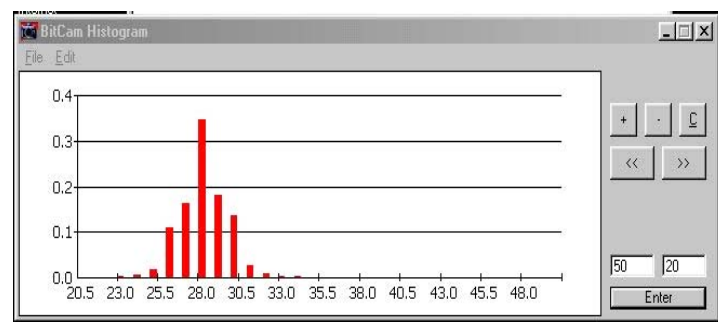
DSNU (dark signal non uniformity) is given in % of maximum signal for a given integration time

Example: Dark current 200-1000 e/s @ 37 ºC, DSNU ~ 1%



Example of a dark image gained digitally





histogram

Data: G Agranov

Temporal Noise

Varies over time - from one image to the other

- Photon noise $\overline{v_{ph}} = \sigma_n q/C = q\sqrt{N}/C$, $\overline{v_{ph}} = (\overline{i_n})t/C = t\sqrt{2qI_{ph}\Delta f}/C$
- Noise in dark current $\overline{v_{drk}} = (\overline{i_{drk}})t/C = t\sqrt{2qI_{drk}\Delta f}/C$
- Reset noise $\overline{v_{nr}} = \sqrt{kT/C}$
- Sampling noise $\overline{v_{ns}} = \sqrt{kT/C}$
- Thermal noise in SF $\overline{v_{sf}} = \sqrt{4kT\frac{2}{3}\frac{1}{g_m}\Delta f}$
- Thermal noise in amplifier $\overline{v_{amp}} = \sqrt{4kT\frac{2}{3}\frac{1}{g_m}\Delta f}$
- Quantization noise $\overline{v_q} = \sqrt{(LSB)^2/12}$

Noise contributions, rms values, are added. Referred to the photo diode (where $G_{tot}=G_{amp}*G_{SF}$):

$$\overline{v_n} = \sqrt{\overline{v_{ph}^2} + \overline{v_{drk}^2} + \overline{v_{nr}^2} + \overline{v_{ns}^2} + \overline{v_{sf}^2} + \overline{v_{amp}^2}(inn)/G_{sf}^2 + \overline{v_q^2}/G_{tot}^2}$$

Given in number of electrons: $e_{rms} = \overline{v_n}/CG = \frac{v_n C_{pd}}{q}$

Temporal noise (cont.)

Noise in dark images

$$\sigma^2_{dark} = \sigma^2_{shot,\,dark} + \sigma^2_{reset} + \sigma^2_{read} \tag{9.1}$$

where

$$\sigma_{shot,\,dark} = \sqrt{N_{dark}}$$ [N = number of generated electrons,]

Noise in illuminated images

$$\sigma^2_{illumin} = \sigma^2_{dark} + \sigma^2_{shot,\,signal}$$

Easy way to determine Conversion Gain. At bright images where noise is dominated by photon noise, we know:

$$v_{signal} = (CG)N_{signal}$$

$$v_{n,\,shot} = (CG)\sqrt{N_{signal}}$$

$$v^2_{n,\,shot} = (CG)^2 N_{signal} = (CG)\ v_{signal}$$

Therefore we can write the Conversion Gain:

$$CG = \frac{v^2_{n,\,shot}}{v_{signal}} \tag{9.2}$$

We find the total conversion factor by the ratio variance to the mean value of the signal (at sufficiently high light levels so that the photon noise dominates the noise).

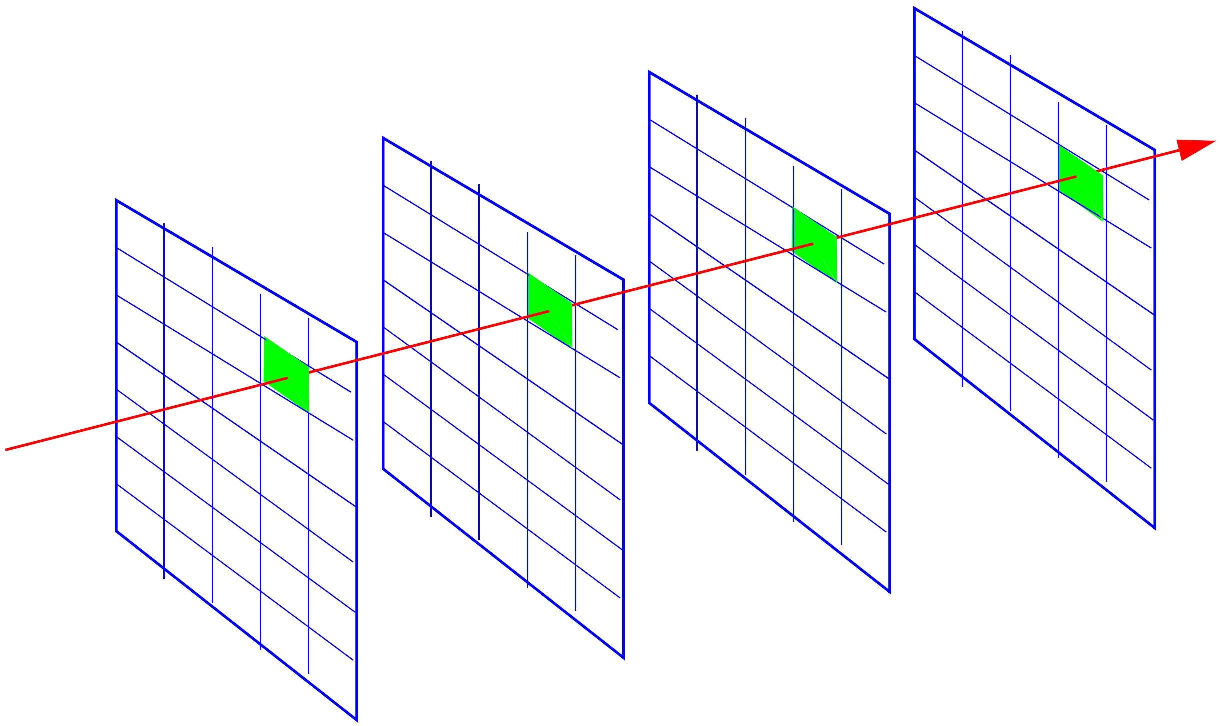
Temporal Noise (cont.)

Measured by taking the rms value from several frames, pixel by pixel. The mean value of the rms values is a measure of the temporal noise.

The method eliminates contributions from FPN.

Optional method

Many pixels within the same frame. The difference between 2 frames removes the FPN.
Divides the results by $2^{1/2}$ because the temporal noise in the two frames is uncorrelated.



Typical values: 10-50 e_{rms}

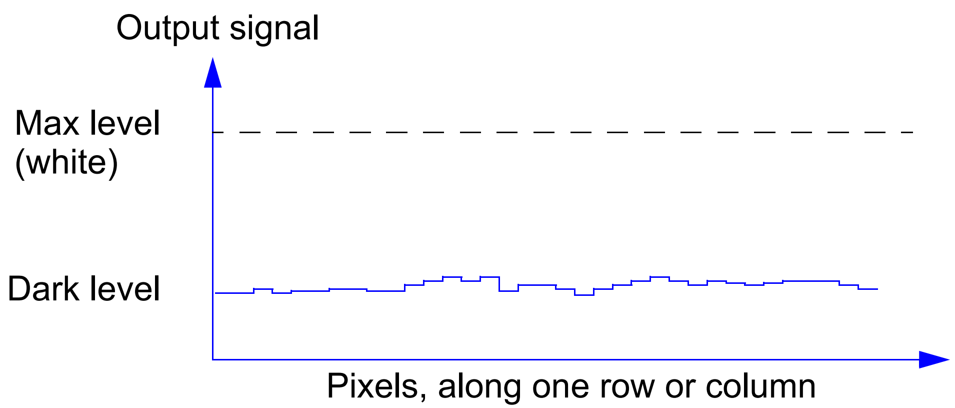
Fixed Pattern Noise - FPN (DSNU)

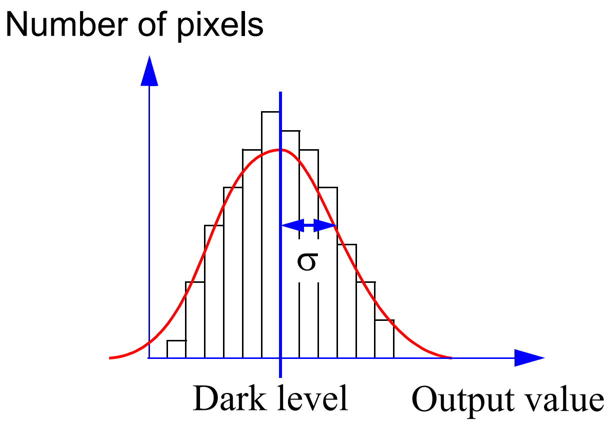
Variations pixel to pixel for a uniformly illuminated sensor.

- Variations in dark signal (DSNU - Dark Signal Non Uniformity)
- Variations in the photo diode's reset level
- Variations in threshold voltage of the SF-transistor

Given as standard deviation in the output signal (Volt or LSBs) across the sensor array.
Take the average of several frames to eliminate temporal noise.

Typical values: < 5 LSB (8 bit), < 2 mV





Data filtering can be used to find the cause of FPN.

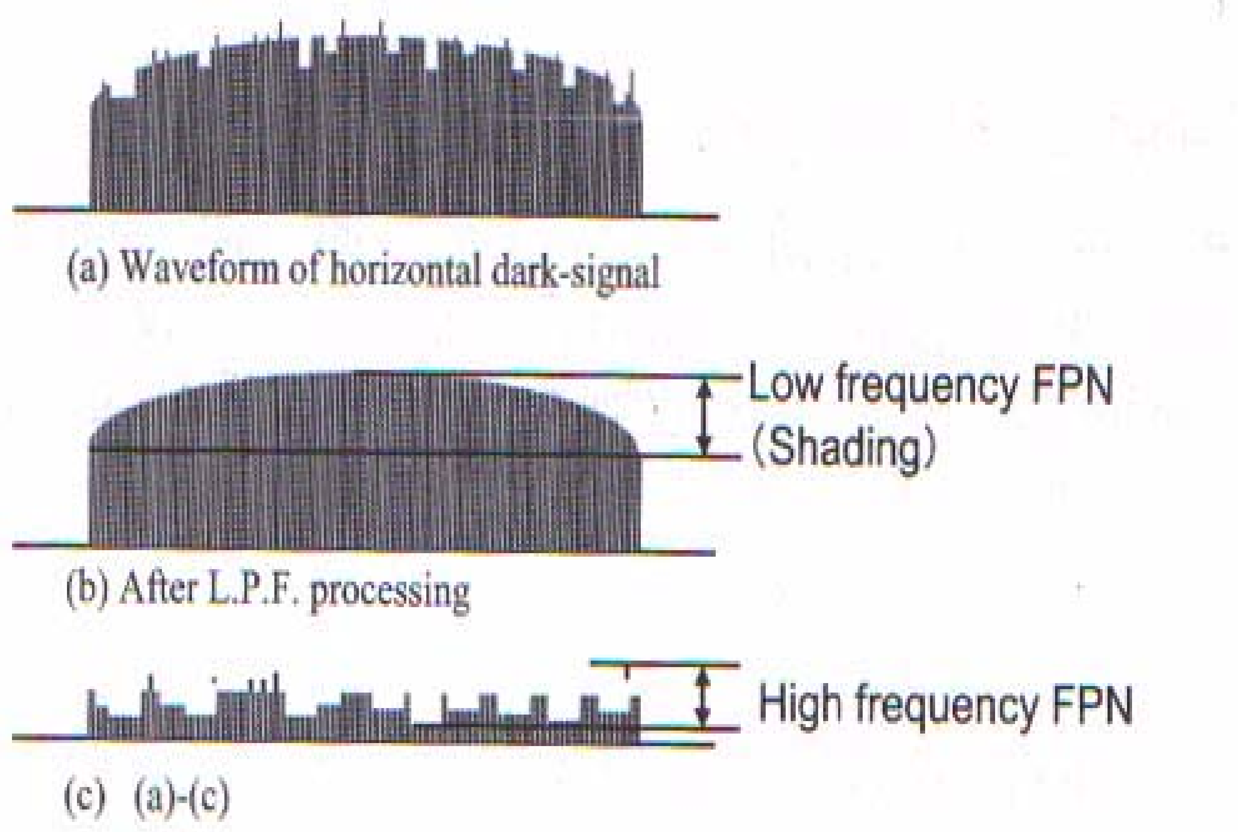
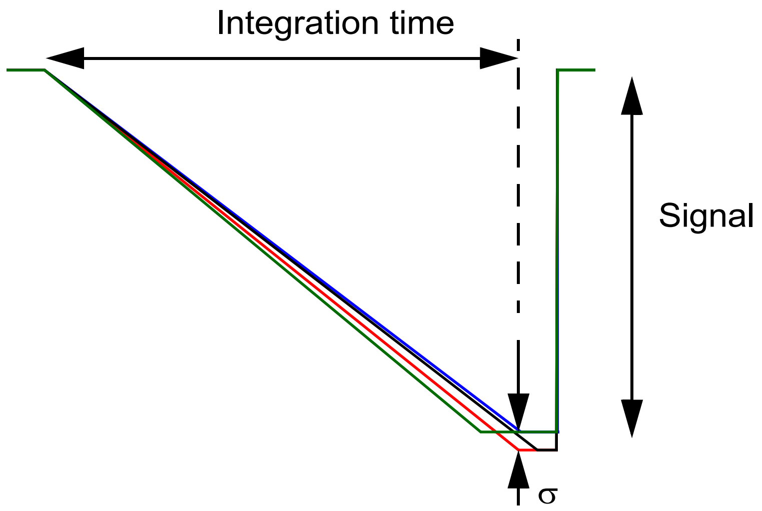


Photo response non-uniformity (PRNU)

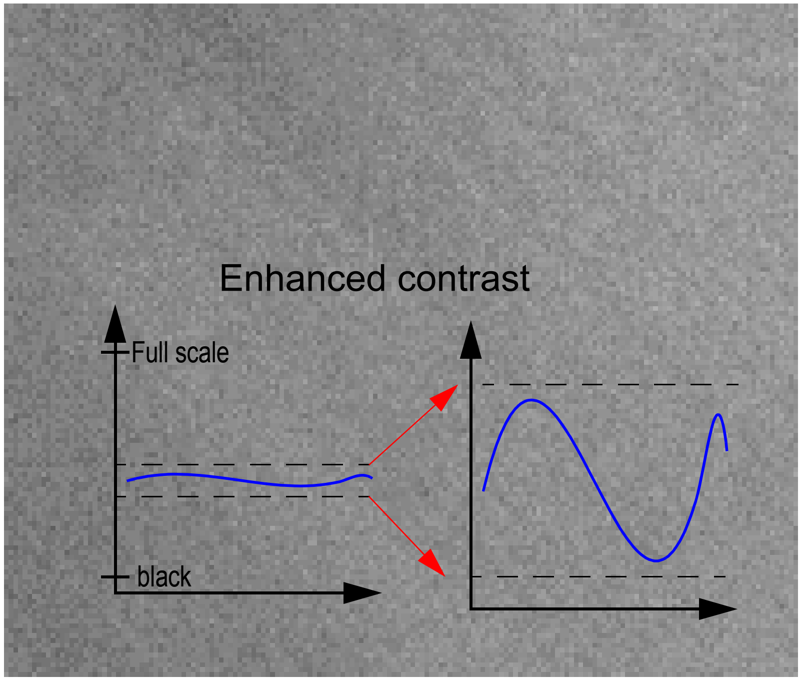


Output signal as a function of light, varies from pixel to pixel. This is caused by variations in:

- Pixel conversion gain (capacitance)
- Source follower threshold voltage and quiescent point.
- Variations in sampling capacitors (column), which determines the gain (with the feedback capacitor).

PRNU rms value of the spread is given in % of full scale (full well).

Typical values are 1-2%



Measurement method

Usage of light box or collimated light. Mean value form several frames removes the temporal noise. Exposure to 50% or 80% of saturation. Measure for all colour planes.

FPN in light sensitivity: Green pixels G_1, G_2

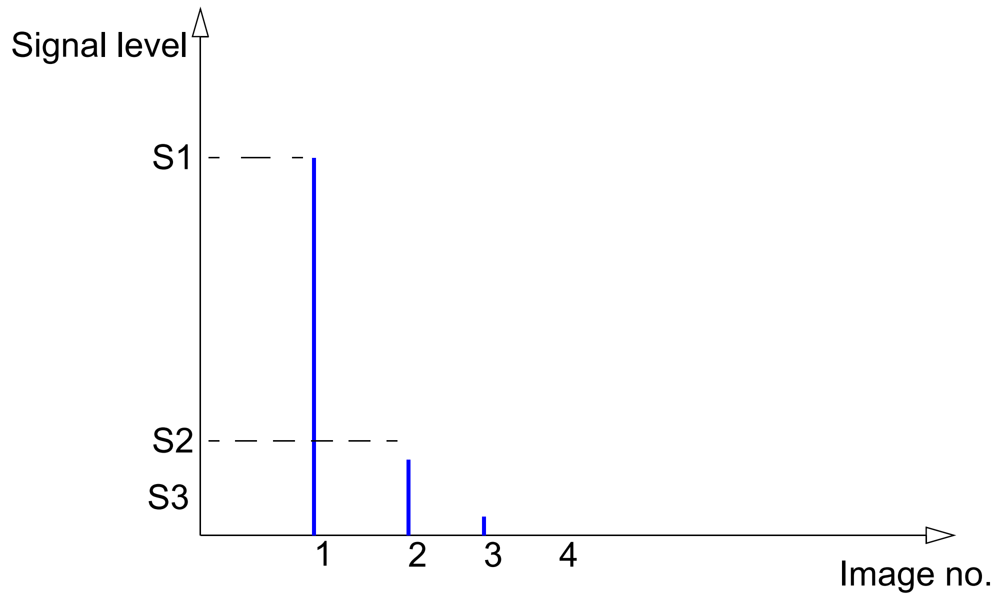
Colour FPN: B-G, R-G or B/G, R/G

White balance and colour processing should be in operation during recording.

LAG

Usage of fast shutter or light diodes

Fist image close to saturation, the succeeding frames in dark.



$$\mathrm{LAG} = \frac{S2}{S1}100 \ [\%] \tag{9.3}$$

IMAGE QUALITY

Some examples

Resolution

- A measure of the smallest detail
- Highest spatial frequency

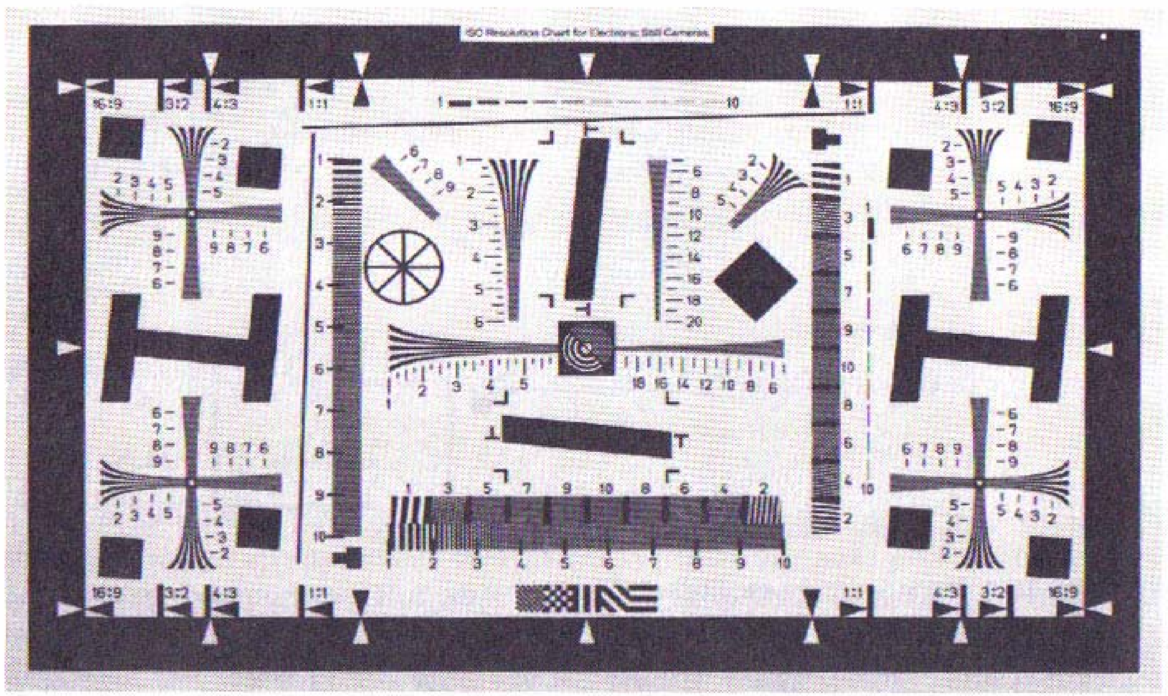
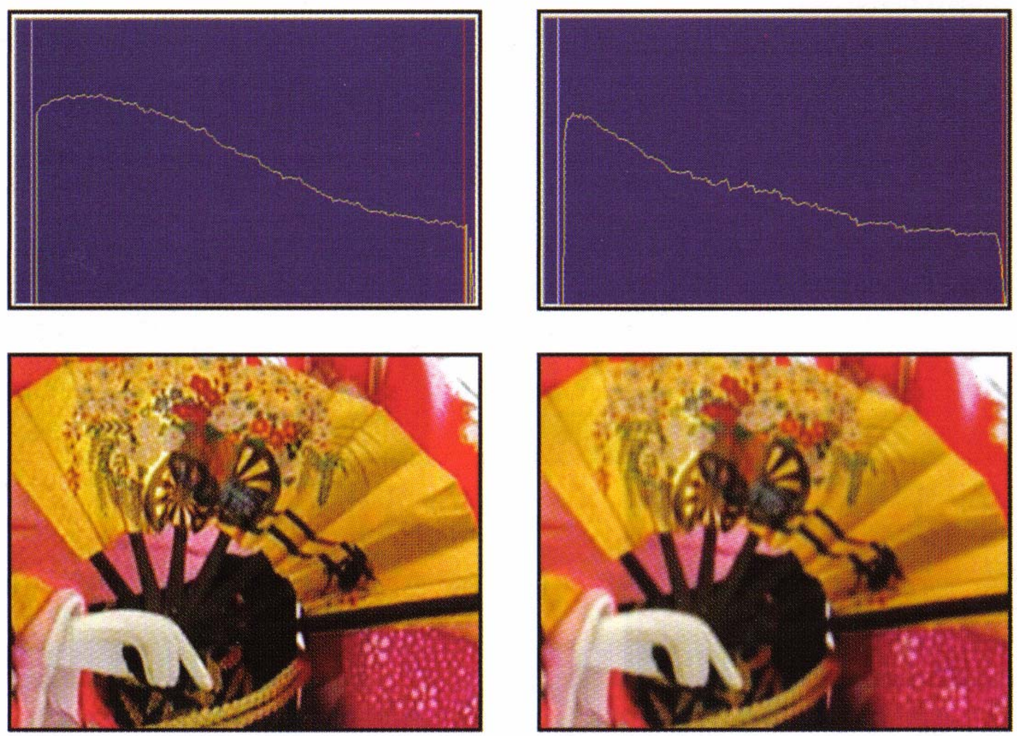


FIGURE 10.2 Appearance of the ISO 12233 test chart.

Frequency response

Important for sharpness, but is different from resolution.



COLOR FIGURE 10.3 Difference of frequency response.

Noise

COLOR FIGURE 10.4 Normal (left) and noisy (right) images.

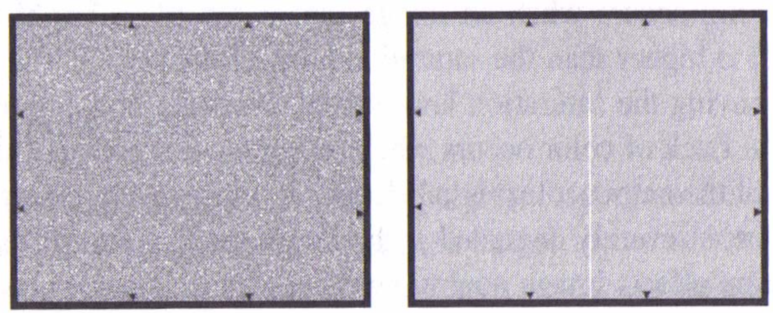
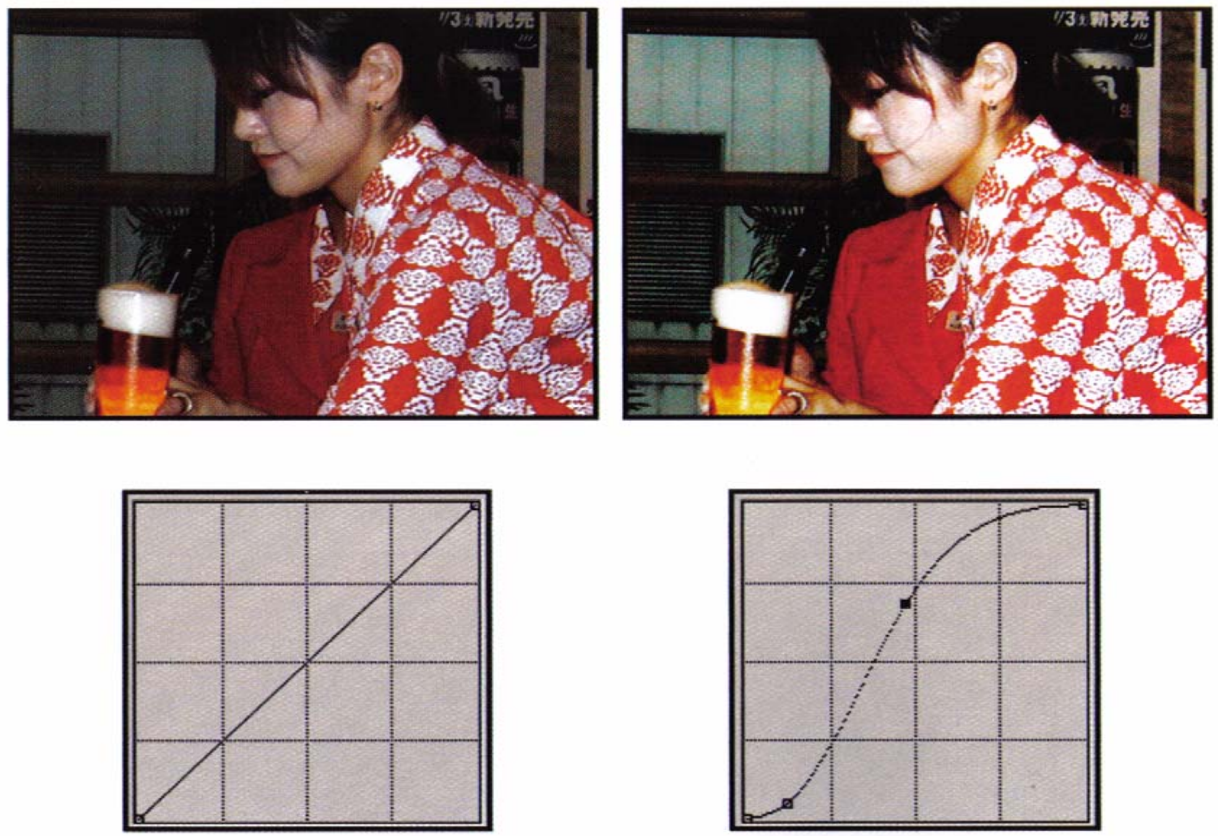


FIGURE 10.13 Examples of spatial random (left) and fixed pattern (right) noise.



COLOR FIGURE 10.5 Original (left) and tone-enhanced (right) images.

Dynamic Range

COLOR FIGURE 10.7 Images with enough (left) and insufficient (right) D-range.

(a) (b) (c)

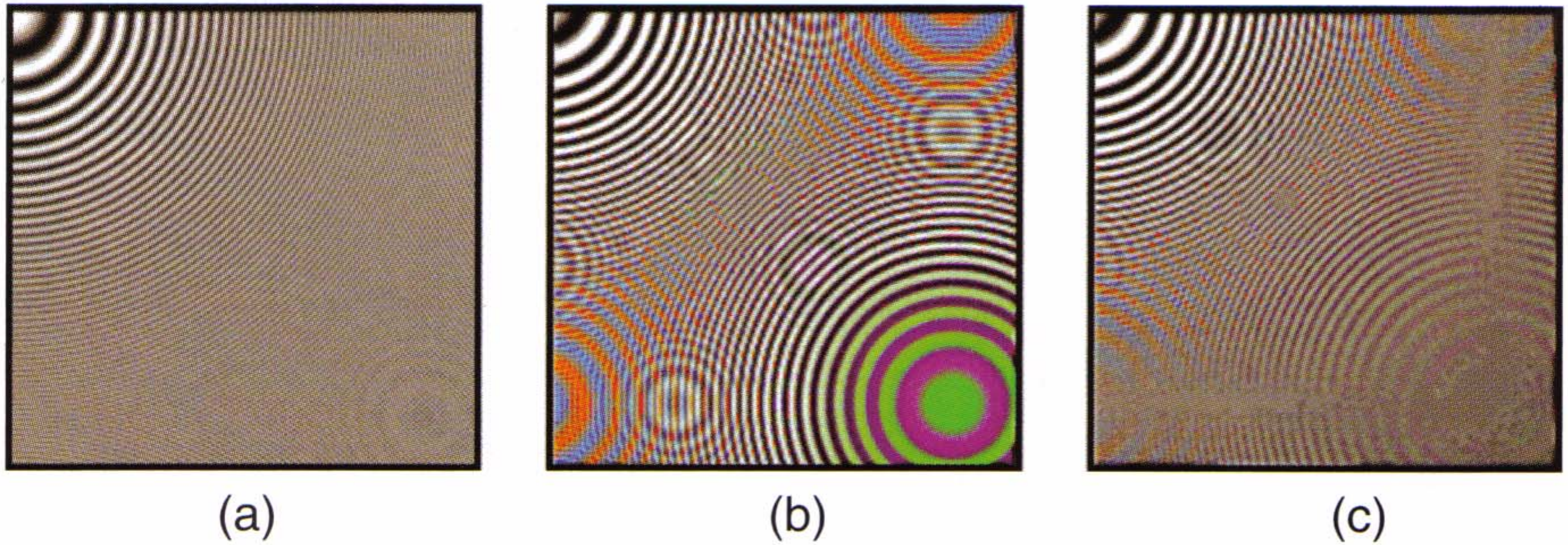
COLOR FIGURE 10.12 Example pictures: (a) with white clipping; (b) wide D-range; (c) with toneless black.

Aliasing - Moiré

Under sampled image results in interference patterns.

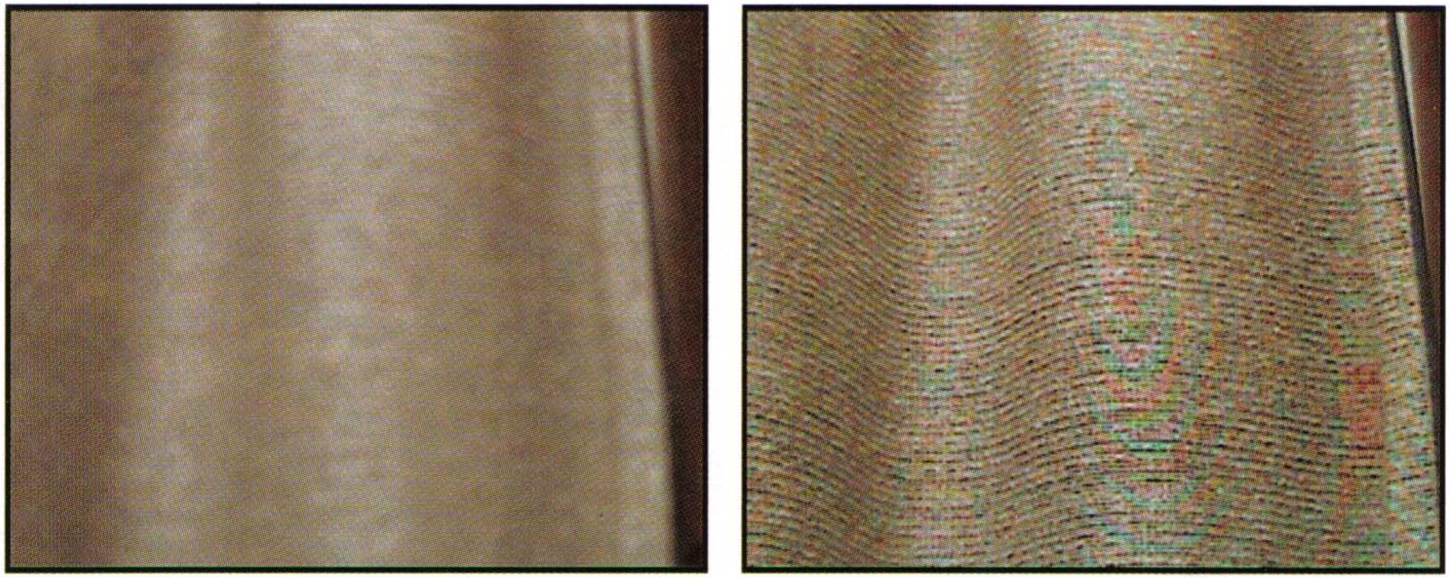
Correctly sampled luminance, but under sampled chrominance, gives interference in the colour reproduction.

Test chart: CZP (circular zone-plate)



COLOR FIGURE 10.9 CZP pattern and examples of generated color moiré: (a) CZP pattern; (b) taken without OLPF; (c) taken with OLPF.

Example of a real image



(a) (b)

COLOR FIGURE 10.10 An example of color moiré in an actual picture: (a) moiré is not observed (out of focus); (b) color moiré generated (in focus).

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