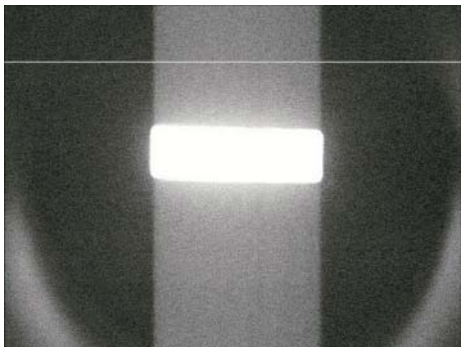
smear

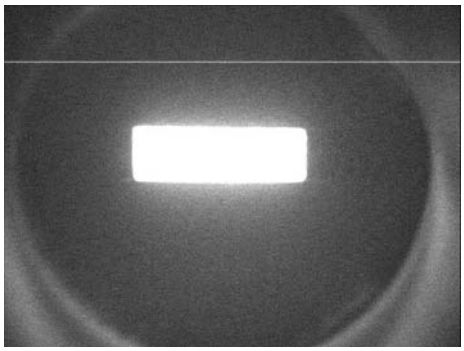
When an interline-transfer-CCD image sensor is read out, the generated charge carriers are transferred from the light sensitive part (photodiode) of a pixel to the shift register. This is located next to the photodiodes and acts like a potential bucket. As there is weak light sensitivity on these shift registers, they are shaded to prevent the additional generation of charge carriers. When the charge transfer to the shift registers is complete, they are vertically shifted, row-by-row, to the horizontal readout line, which is then read out serially. This row-by-row vertical shifting is comparable to an endless conveyor belt. With every shift step, all registers are shifted by one register location, including those register rows that were previously drained from the image.

If an intense light source is imaged onto the CCD image sensor, this can generate unwanted charge carriers in the shielded shift registers (mainly due to the scattering of light on the CCD chip) in every line or row that is shifted below the spot. This results in additional unwanted light signals called "smear". Smear can be recognized as bright vertical bands below and/or above the bright image spot (interline or frame transfer architecture). Smear is dependent on the light intensity (therefore short exposure time, high intensity, more smear - long exposure time, low intensity, less smear), image sensor readout time or speed (slow readout, more time for smear - fast readout, less time for smear) and the corresponding structure of the image sensor (quality and presence of microlenses influences the light scattering properties and therefore smear). In general, it is a characteristic of the applied image sensor.

with smear



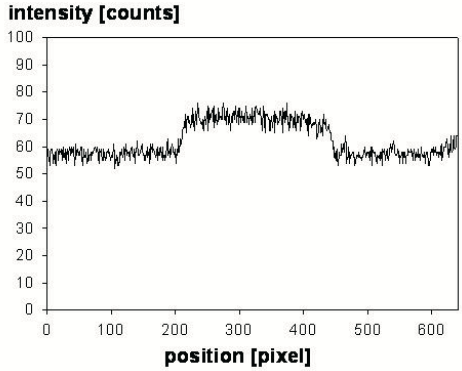
without smear



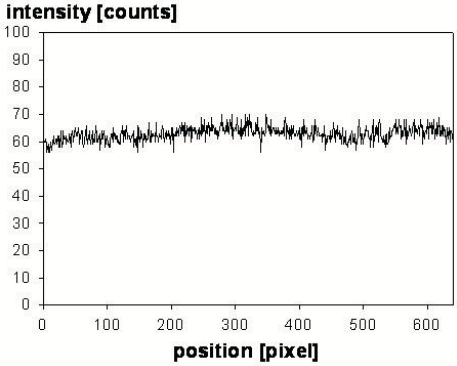
The left image shows a back illuminated rectangular aperture with an exposure time of 1 ms in a stretched scaling (48-100 counts correspond to 0-255 gray levels). The white line illustrates the position of the row of pixels which has been extracted to be shown in the next graph. The right image shows the same aperture, with the same scaling, at 100 ms exposure time and reduced back illumination. The resulting right image generally has the same intensity values as of the left image (see graphs on next page). To achieve this same gray level, the intensity of the light had to be 100x higher and caused 100x more smear. The circular structure visible within the outer regions of the images are caused by reflections within the set-up.

smear

with smear



without smear



The graphs show the results of the rows of pixel read out data of both aperture images, with different exposure times. The left graph clearly shows the step-like signal increases due to smear (smear approximately equal to 10-12 counts), while the dark value is similar for both images (58-62 counts).

The two photos show the same images of the aperture from the first example, using a different scaling (0-255 gray levels correspond to 0-2500 counts). The left image was taken with an exposure time of 1 ms, while the right image was exposed for 100 ms with reduced illumination.

Smear Reduction and Prevention

1. Reduction of light signal

If the strong light signal is reduced or removed, smear will be reduced or removed too.

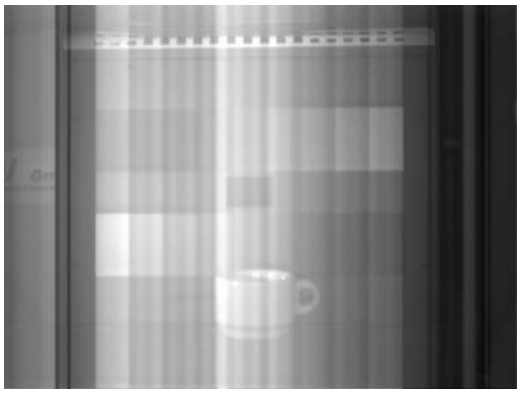
2. Extension of exposure time

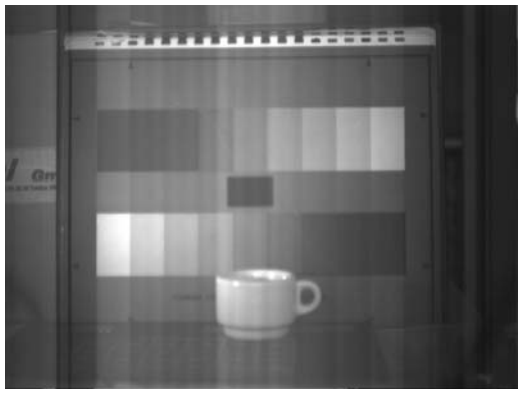
The main relationship of interest for smear estimation is the relation of light intensity vs. image sensor readout time. The latter can only be changed by change of pixelclock and if available two ADC readout instead of one ADC readout. The former can always be adjusted by the user (e.g. exposure time control).

smear

To illustrate this relationship, the following two sample images, which have been recorded with the same camera, are displayed. When the illumination is constant, smear can be reduced by increasing the readout speed and therefore decreasing the image sensors readout time. Another option is the decrease of the illumination (e.g. closing of aperture) and subsequent increase of the exposure time.

with smear **less smear**



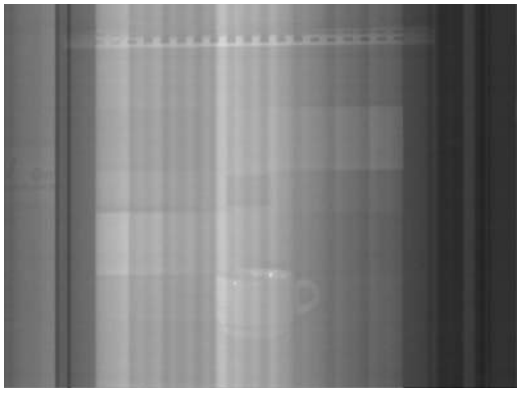


The two images illustrate the effect on smear, when the exposure time stays constant and the image sensor readout time is changed. The left image was recorded at an exposure time of 50 µs with one ADC readout at 10 MHz, while the right image was recorded at the same exposure time but with two ADC readout at 2 x 40 MHz.

3. Turn Off the light During Readout

The light signal can be masked or turned off after the exposure is finished. This way, no light will hit the sensor before and after exposure, while the image is read. Current digital still cameras use mechanical shutters for this purpose. The two images below illustrate this.

with smear **without smear**



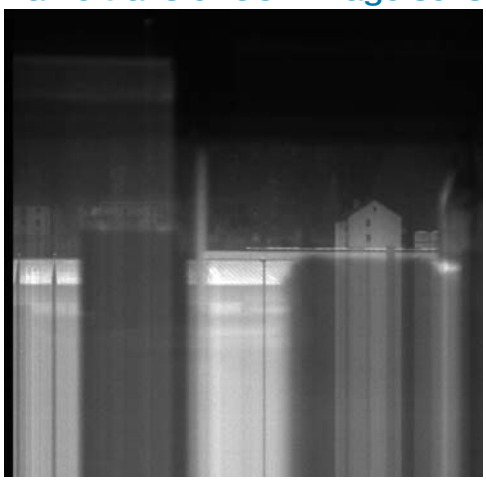
The two images illustrate the effect on smear, when the light is switched off during image sensor read out. The left image was recorded at an exposure time of 5 µs with continuous illumination of the scene, while the right image was recorded at the same exposure time but illuminated with a flash light.

smear

Smear in Frame-Transfer CCD Image Sensors

The previous explanation applies only to smear in interline-transfer CCD image sensors, which are suited for high speed applications as opposed to frame-transfer CCD image sensors (typ. time for one frame-transfer is at minimum 1 ms). Smear also exists in frame-transfer CCD image sensors, but is not symmetrical. In frame-transfer CCD image sensors, the light sensitive cells are shift registers themselves. Within the frame-transfer process, the entire image is transferred in total (frame transfer). Technically, this means a fast clocked row-by-row shifting into the shielded storage area. In contrast to the interline-transfer process, the image is shifted just below the bright image spot for the readout process, which does not influence the first readout rows. Measures against smear are similar to those described herein.

frame transfer CCD image sensor with smear



Smear in CMOS Image Sensors

In CMOS image sensors, each pixel is adressed and read out directly, preventing any shift below the bright image spots. The direct readout prevents the generation of smear in CMOS image sensors.