Interline Image Sensor: KAI-1003M

Dark Current vs. Temperature

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1. Description

Dark current generated in a KAI-1003M device, as is the case with all CCD imagers, is highly temperature dependent. It includes two components: one is generated from photodiodes and the other is from the CCD shift registers. This note investigates the mean value and temperature dependence of each of these components. The temperature was varied from –10°C to 60°C. The horizontal shift register (HCCD) clocking rate was 1Mhz. The vertical shift register (VCCD) clocking rate was approximately 0.8Khz with an effective integration period of 1.5 second. All other operating parameters were set to their nominal values. The device timing was arranged such that horizontal overclock and vertical overclock periods were formed outside of the normal active pixel clocking periods. These overclock periods allow for measurement of the HCCD and VCCD dark currents independently. Since the HCCD is typically clocked continuously, at a high rate, the dark current contribution from this region is not of major concern, however for completeness, its effects are included in this investigation. Hence, when clocking out the device, three regions of interest were defined separately in the active area, horizontal, and vertical overclock areas. The respective dark current generation rates for the photodiode (Ipd) and the VCCD (Ivccd) can be obtained by:

$$Ipd(e/pix/s) = (Vact - Vvccdovk)(adu/pix) / Tint(s) * K(e/adu), \quad (1)$$

$$Ivccd(e/pix/s) = (Vvccdovk - Vhccdovk)(adu/pix) / Tint(s) * K(e/adu), \quad (2)$$

where Vact, Vvccdovk and Vhccdovk correspond to signal values in active area, vertical overclock and horizontal overclock regions, Tint is integration time, and K is a constant for a specific system gain.

Figure 1 shows a dark image of a KAI-1003M device with the three regions of interest chosen, within the active, vertical over clock and horizontal over clock areas. Sizes of the regions of interest can vary depending upon the repeatability of test results for each individual test system. The location of each box was set near the center of each area for this investigation.

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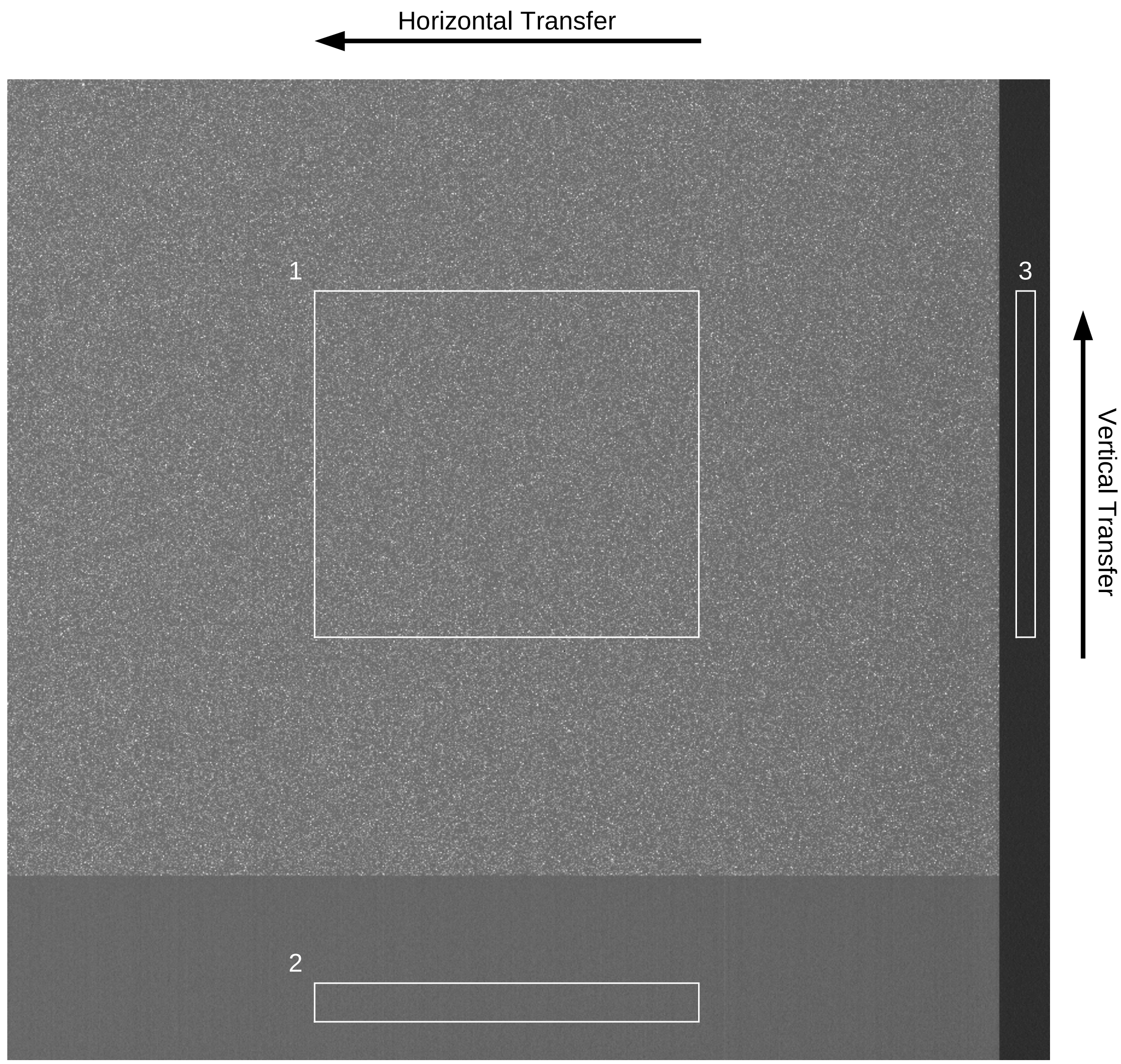

Figure 1.
An image from a KAI-1003M using both horizontal and vertical overclocking. Three regions of interest were defined to calculate dark current components from the photodiodes and vertical CCD registers of KAI-1003M devices. Box 1 is in the active area, box 2 is in the vertical overclock area, and box 3 is in the horizontal overclock area. The sizes of boxes can vary.

2. Results

Figure 2 shows the results of the temperature dependence of dark current generation rates from the photodiodes and the VCCD registers. The dark current has been normalized to the pixel area and hence is expressed in electrons per pixel per second. On average, the VCCD has 10X the dark current contribution as that of the photodiodes in the low temperature range around 0°C. The VCCD dark current increases faster than that of the photodiodes when temperature increases. At 60°C, the ratio of the VCCD dark current over the photodiode dark current is approximately 100X. At 30°C, the doubling rate for the VCCD is approximately 6°C where as for the photodiodes, the doubling rate is approximately 8°C.

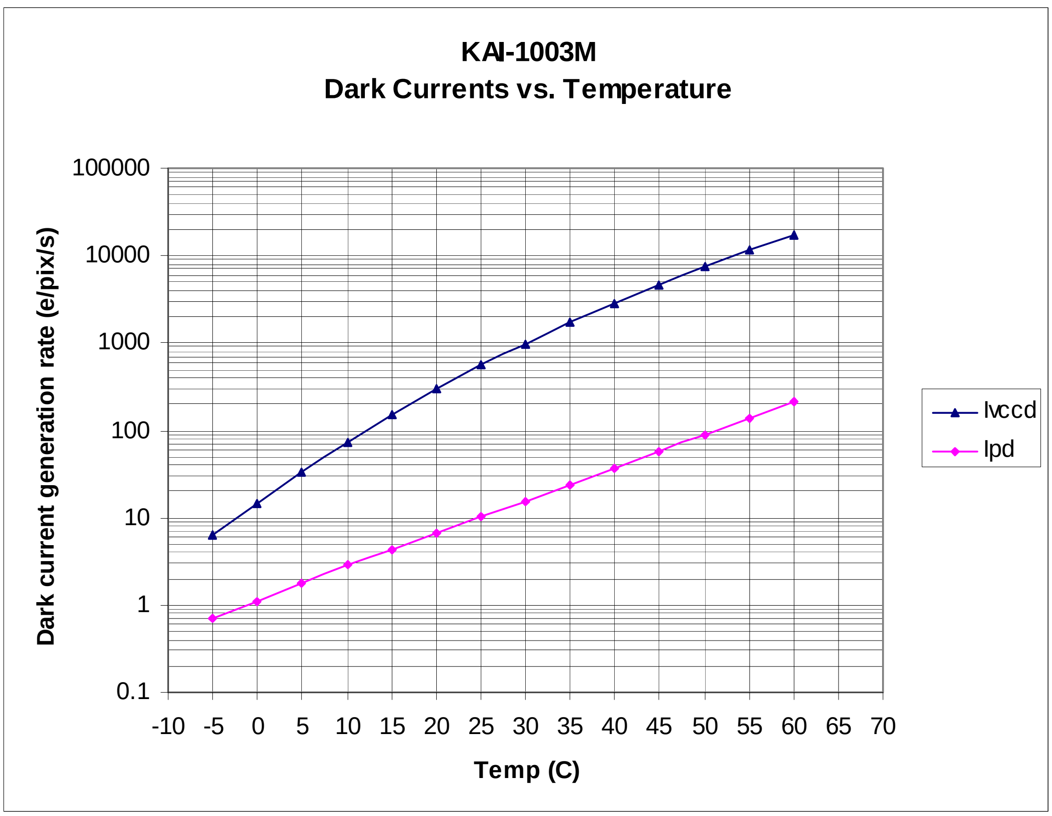

Figure 2.

The temperature dependence of dark currents generated from both the photodiodes and the vertical CCD registers is shown for the KAI-1003M device.

3. Estimating Dark Current Signal Levels

Dark currents generated from the photodiodes and vertical CCD registers under certain frame rates and temperature conditions can be estimated by the following equations:

$$Dpd(e/pix) = Ipd\ (e/pix/s) * Tint\ (s) \quad (3)$$

$$Dvccd(e/pix) = Ivccd\ (e/pix/s) * Tr\ (s) \quad (4)$$

$$Dtot(e/pix) = Dpd(e/pix) + Dvccd\ (e/pix) \quad (5)$$

where Dpd, Dvccd, and Dtot represent the dark current (in electrons) from the photodiodes, vertical CCD registers and the total, respectively. Ipd and Ivccd are the dark current generation rates at certain temperature for photodiodes and vertical CCD registers, which can be obtained from the graphs in Figure 2. Tint is the photodiode integration period and Tr is the frame readout period.

Three sample calculations are shown below:

Example 1. Pixel rate 20Mhz/output, two outputs, 25°C, Tint=Tr, camera frame size (horizontal x vertical) = 1024 x 1024

For two outputs at pixel rate 20Mhz, the readout time is:

Tr=612 (pix/line)*1036(line/frame)*(sec/pix)/(20*10^6)=31.7ms

(Refer to page 6 of the KAI-1003M specification).

From Figure 2, at 25°C, dark current generated from the photodiodes is approximately 10e/pix/s. Therefore for each frame captured, dark current is:

10*0.0317 = 0.3 e/pix.

Similarly, dark current generated from the vertical CCD registers at this temperature is approximately 550 e/pix/s. For each frame, it contributes

550*0.0317 = 17.4 e/pix.

In total then, there are approximately 18 electrons of dark current signal generated for each frame when a KAI-1003M device is operated at above condition.

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Example 2. Pixel rate 1Mhz/output, 1 output, 25°C, Tint=Tr, camera frame size (horizontal x vertical) = 1024 x 1024

For one output at pixel rate 1Mhz, the readout time is:

Tr=1140(pix/line)*1036 (line/frame)*(sec/pix)/10^6 =1.2s.

The dark current from the photodiodes for each frame is:

10*1.2=12 e/pix

and that from the vertical CCD registers is:

550*1.2=660 e/pix.

The total dark current for each frame captured at above condition is approximately 672 electrons of dark signal, with the primary component coming from the vertical CCD registers.

Example 3. Pixel rate 1Mhz/output, 1 output, -5°C, Tint=5 minutes, camera frame size (horizontal x vertical) = 1024 x 1024

For one output at pixel rate 1Mhz, the readout time is:

Tr=1.2s (see Example 2).

At –5°C**,** the dark current from the photodiodes is approximately 0.7 e/pix/s and that from the vertical CCD registers is approximately 6 e/pix/s. Since the integration time is 5 minutes for each frame, the dark current from the photodiodes is:

0.7*5*60=210 e/pix.

The dark current contribution from the vertical CCD registers is: 6*1.2=7.2 e/pix.

Therefore, the total dark current for each frame captured at above condition is approximately 217 electrons of dark signal, with primary component coming from the photodiodes.

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4. Summary

The dark current for the KAI-1003M has been characterized as a function of temperature. The two components of the dark current have been identified wherein the VCCD component has been shown to have a higher generation rate, by nearly a factor of 10 at temperature around 0°C and a factor of 100 at temperature around 60°C. However, depending upon the application and integration period, either component may dominate. A simple calculation, based on the examples above, ensures proper treatment of dark current for a given application.