AND9192/D

Estimating Dark Current from Operating Temperature

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APPLICATION NOTE

Description

Dark current generated in CCD imagers, is highly temperature dependent. It includes two components: one is generated from photodiodes and the other is generated from the CCD shift registers. This note investigates the mean value and temperature dependence of each of these components for the KAI−1003 and KAI−02150 image sensors.

For the KAI−1003, the temperature was varied from −10°C to 60°C. The horizontal shift register (HCCD) clocking rate was 1 MHz. The vertical shift register (VCCD) clocking rate was approximately 0.8 kHz with an effective integration period of 1.5 seconds. 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, horizontal overclock, and vertical overclock areas. The respective dark current generation rates for the photodiode (Ipd) and the VCCD (Ivccd) can be obtained by:

$$Ipd(e^-/pix/s) = (Vact - Vvccdovk)(adu/pix) / \\ / Tint(s) * K(e^-/adu) \quad \text{(eq. 1)}$$

$$Ivccd(e^-/pix/s) = (Vvccdovk - Vhccdovk)(adu/pix) / \\ / Tint(s) * K(e^-/adu) \quad \text{(eq. 2)}$$

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−1003 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. 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 location of each box was set near the center of each area for this investigation. The sizes of boxes can vary.

Using the same approach, dark current components were measured for KAI−02150 and the results can be seen in Figure 3.

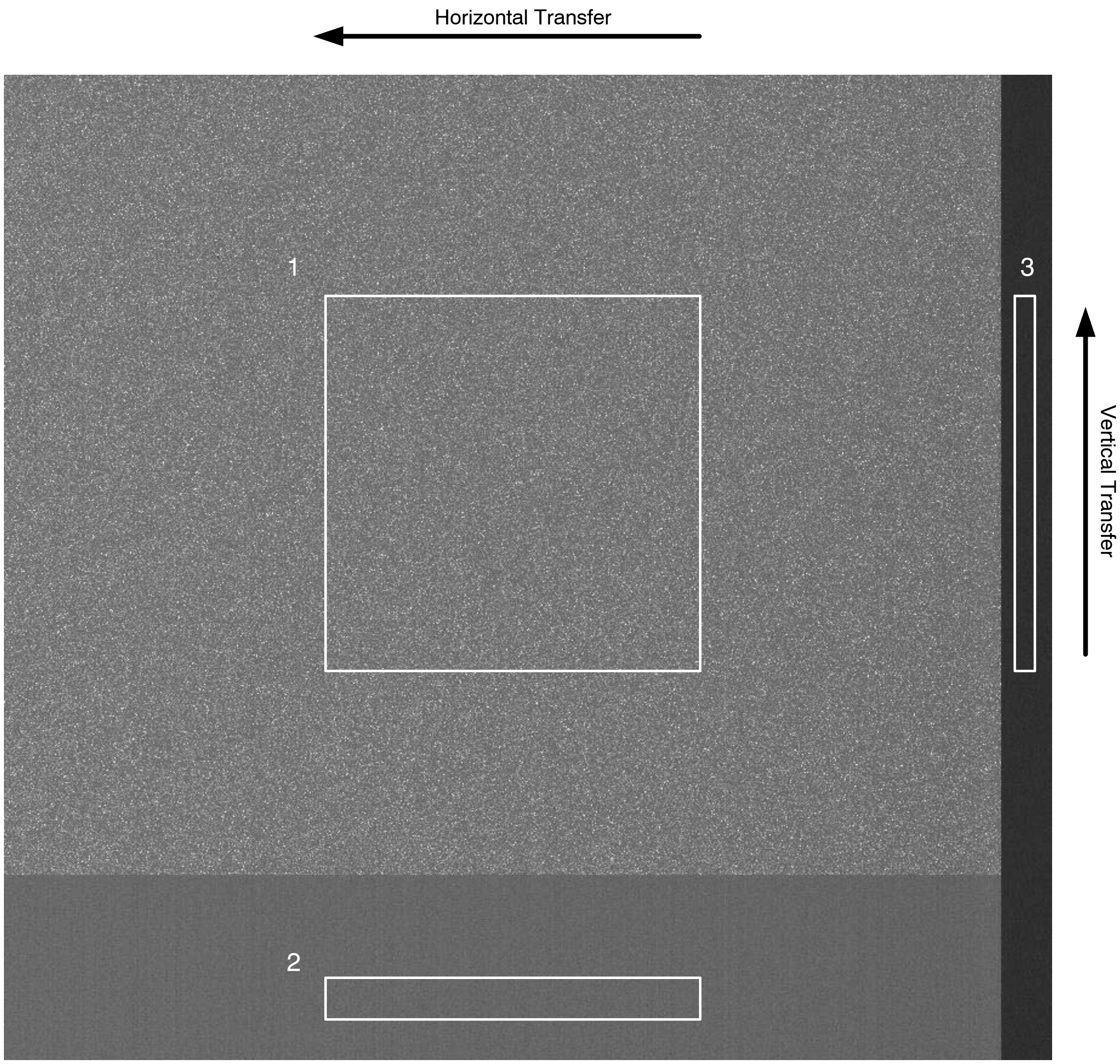

Figure 1. Image from KAI−1003 using both Horizontal and Vertical Overclocking

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.

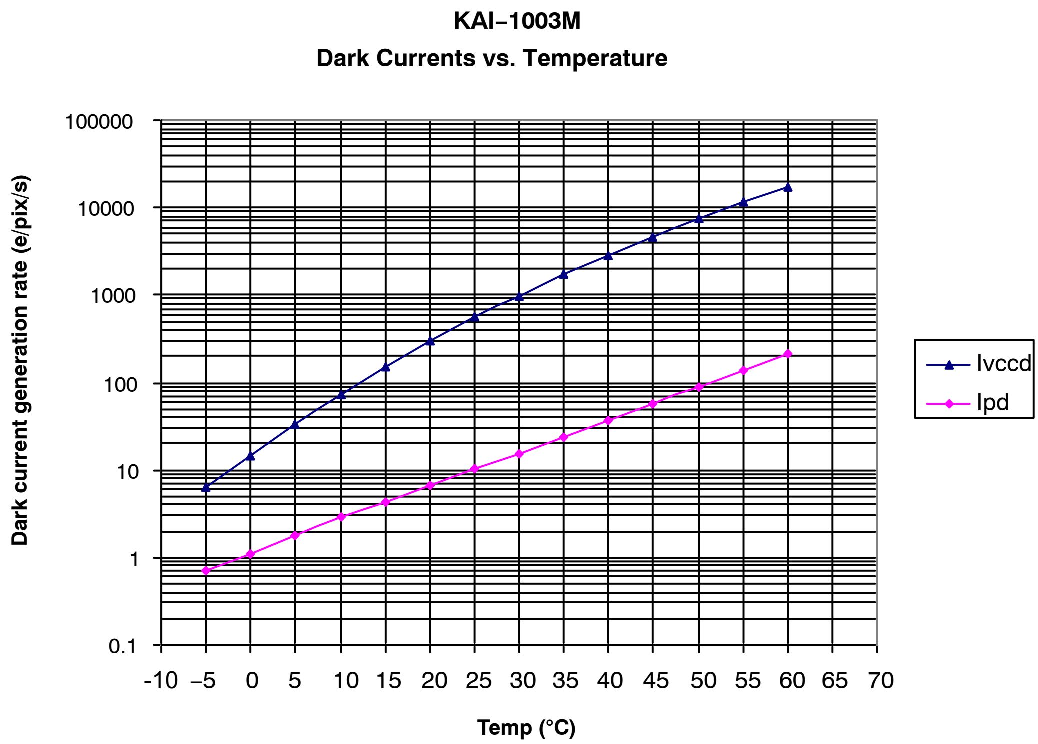

Figure 2. Dark Current Temperature Dependence for KAI−1003

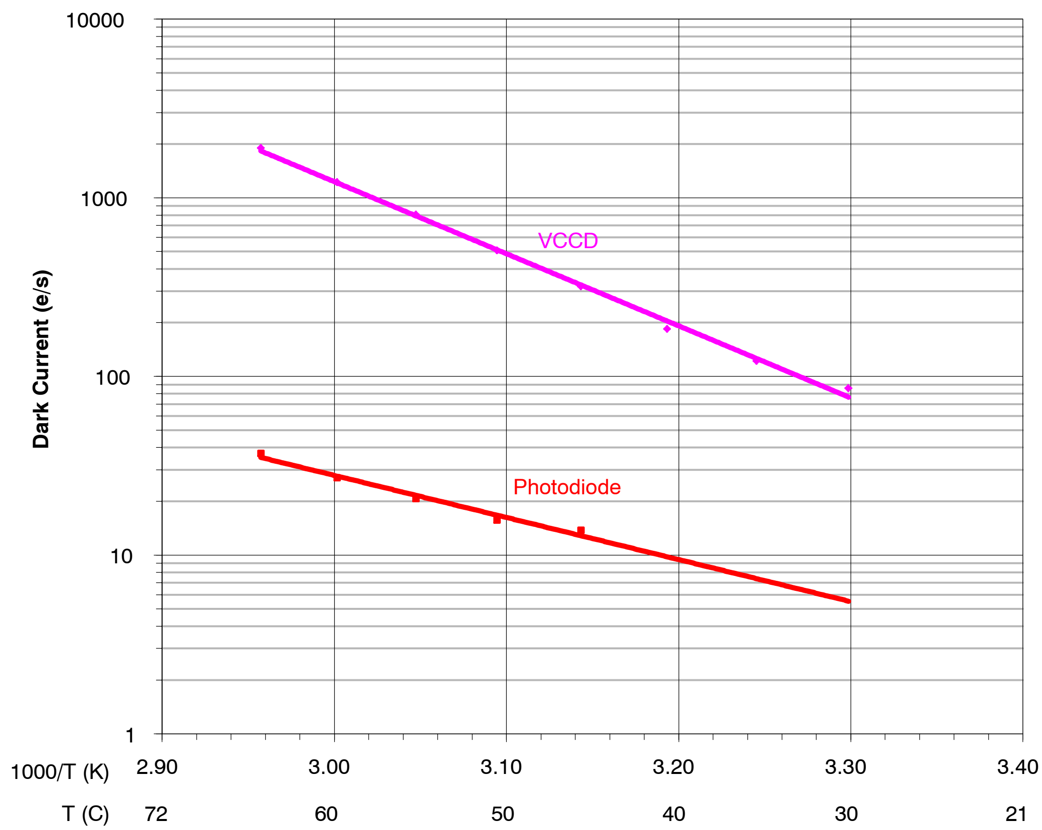

Figure 3. KAI−02150 Dark Current

The temperature dependence of dark currents generated from both the photodiodes and the vertical CCD registers is shown for the KAI−02150 device.

For this diagram the temperature is shown using 1/T in order to show a more linear plot in the Log diagram. On the tip of the diagram 60, 50 and 40°C are indicated as reference.

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:

$$Dpd(e^-/pix) = Ipd(e^-/pix/s) * Tint(s) \quad \text{(eq. 3)}$$

$$Dvccd(e^-/pix) = Ivccd(e^-/pix/s) * Tr(s) \quad \text{(eq. 4)}$$

$$Dtot(e^-/pix) = Dpd(e^-/pix) + Dvccd(e^-/pix) \quad \text{(eq. 5)}$$

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.

Sample calculations are shown below.

Example 1

In case of KAI−1003 at pixel rate 20 MHz/output, two outputs, 25°C, Tint = Tr, camera frame size (horizontal x vertical) = 1024 x 1024.

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

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

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

From Figure 2, at 25°C, dark current generated from the photodiodes is approximately 10 e^-/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−1003 device is operated at above condition.

Example 2

In case of KAI−1003 at pixel rate 1 MHz/output, one output, 25°C, Tint = Tr, camera frame size (horizontal x vertical) = 1024 x 1024

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

Tr = 1140 (pix/line) * 1036 (line/frame) * (sec/pix) / 106 = = 1.2 s

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

In case of KAI−1003 at pixel rate 1 MHz/output, one output, −5°C, Tint = 5 minutes, camera frame size (horizontal x vertical) = 1024 x 1024

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

Tr = 1.2 s (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.

Example 4

In case of KAI−02150 at pixel rate 40 MHz/output, two outputs, 40°C, Tint = 31 ms

(Refer to page 31 of the KAI−02150 specification)

From Figure 3 at 40°C, dark current generated from the photodiodes is approximately 9 e^-/pix/s. Therefore for each frame captured, dark current is:

9 * 0.031 = 0.33 e^-/pix

Similarly, dark current generated from the vertical CCD registers at this temperature is approximately 200 e^-/pix/s. For each frame, it contributes

200 * 0.031 = 6.2 e^-/pix

In total then, there are approximately 6.53 electrons of dark current signal generated for each frame when a KAI−02150 device is operated at above condition.

Example 5

In case of KAI−02150 at pixel rate 40 MHz/output, two outputs, 60°C, Tint = 31 ms
(Refer to page 31 of the KAI−02150 specification)

From Figure 3 at 60°C, dark current generated from the photodiodes is approximately 30 e^-/pix/s. Therefore for each frame captured, dark current is:

30 * 0.031 = 0.93 e^-/pix

Similarly, dark current generated from the vertical CCD registers at this temperature is approximately 1050 e^-/pix/s. For each frame, it contributes

1050 * 0.031 = 32.55 e^-/pix

In total then, there are approximately 33.48 electrons of dark current signal generated for each frame when a KAI−02150 device is operated at above condition.

Example 6

In case of KAI−02150 at pixel rate 40 MHz/output, four outputs, 60°C, Tint = 15.5 ms
(Refer to page 31 of the KAI−02150 specification)

From Figure 3 at 60°C, dark current generated from the photodiodes is approximately 30 e^-/pix/s. Therefore for each frame captured, dark current is:

30 * 0.0155 = 0.46 e^-/pix

Similarly, dark current generated from the vertical CCD registers at this temperature is approximately 1050 e^-/pix/s. For each frame, it contributes

1050 * 0.0155 = 16.3 e^-/pix

In total then, there are approximately 16.7 electrons of dark current signal generated for each frame when a KAI−02150 device is operated at above condition.

SUMMARY

The dark current for the KAI−1003 and KAI−02150 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.

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