Measurement of noise and gain of the APDCAM detector camera as a function of temperature and detector bias

Fusion Instruments Kft.

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This note describes measurements made with a 100 kHz bandwidth APDCAM detector camera where the analog amplifier board was optimized for low light level. Under these conditions the shot noise of the detector leakage current starts to determine the noise level at zero light. As the gain and leakage current are both sensitive to the detector temperature this white paper investigates the beahaviour at various temperatures.

Measurements were made at different detector temperatures (13, 18, 23, 28 C) with closed shutter and fixed calibration light setting. The detector bias voltage was ramped from 200 to 430 V which is over the standard 50 gain value. At each temperature and bias setting the mean and standard deviation of the 32 pixel signals were determined from measurement with 100 000 samples. To determine the offset level the measurements were repeated with 0 calibration light level as well. Measured values were averaged over the 32 pixels to reveal the average beahaviour. The results are summarized in the plot on the next page.

The light signal was determined as the difference in signal with light on and off shown in the lower left plot. The light signal as a function of bias voltage gives the relative detector gain change as a function of bias voltage. The gain clearly increases with decreasing temperature. Although the S8550 detector does not have a temperature calibration, this beahaviour is known from other Hamamatsu APD detector datasheets. Comparing the curve with detector factory data we assumed a maximum gain of 100 and obtained the absolute detector gain as a function of bias voltage.

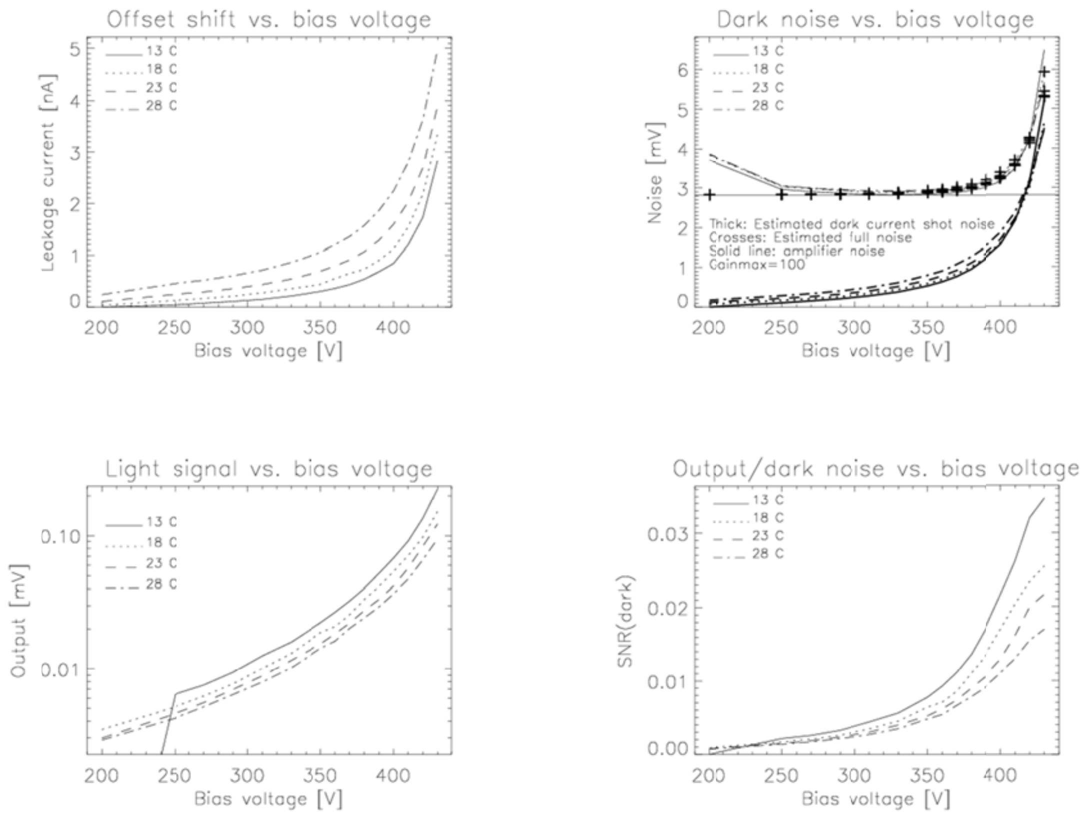
We assume that the offset change as a function of bias voltage is caused by the amplified leakage current. (In APDCAM cameras set for higher light level there is no offset shift as a function of bias voltage.) Assuming that at the lowest bias voltage the amplified leakage current is negligible we calculate the leakage current from the APDCAM transimpedance gain and the detector gain. The upper left plot shows the calculated leakage current as a function of voltage for different temperatures. The leakage current increases with temperature.

The curves on the upper right plot show the noise level in the offset measurements as a function of detector voltage for different temperatures. These curves are very close to each other. The qualitative explanation is the following. At lower temperatures the leakage current is lower, therefore the shot noise is also lower. This descrease is compensated by the increasing gain. To further check this the thick curves shown the estimated leakage current noise. It is calcualted as

$$n_l = \sqrt{(I_l / G)\tau / e} \cdot Ge / \tau ,$$

where I_l is leakage current, G is the detector gain, τ is the time constant of the amplifier ($\tau=1/(2\pi BW)$, where BW is the bandwidth) and e is the electron charge. The crosses in the figure show the estimated noise level as a result of both the amplifier noise and the leakage current shot noise. The amplifier noise is estimated as the minimum noise in the offset measurements. The plot shows very good agreement between the estimated and measured dark (offset) noise therefore we can conclude that the increase in noise level at high voltage is the result of the leakage current shot noise.

The plot on the bottom right shows the ratio of the light signal to the dark noise. For these low signal levels the noise is dominated by the dark noise therefore it is a good estimation for the signal-to-noise ratio (SNR). It is clearly seen that the SNR significanly increases when the detector is cooled. This comes from the fact the the detector gain increases while the dark noise is nearly independent of the temperature.



It has to be noted that APDAM is not designed for low temperature detector operature therefore condensation might cause problems. According to experience the camera can safely be operated at 10-15 C temperatures for several hours. After such operation a similarly long decondensation period with about 40 C detector temperature and open shutter is recommended to remove any condensed humidity. However, it has to be noted that the manufacturer cannot take responsibility for damages caused by condensation.