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ELIS-1024 – Maximizing Signal to Noise via Non-Destructive Readout Application Notes of ELIS-1024 High Performance 1024x1 Line Scan CMOS Image Sensor

This note describes temporal/random noise reduction of the ELIS-1024 image sensor using NDRO mode. This is especially useful when using the sensor for detecting very weak signals as may be encountered in Spectroscopy and related applications.

The ELIS-1024 sensor provides user access to all the key sensor timing and control functions needed to operate the sensor is a variety of ways that cannot be achieved by a typical CCD sensor. Key differences between the ELIS-1024 and a 'high performance' CCD are as follows

1. The ELIS-1024 sensor does not bloom or streak as readily as CCD would under overloaded conditions. Therefore individual pixels can saturate while adjacent pixels are minimally affected.
2. ELIS-1024 can be read non-destructively. The ELIS-1024 samples the accumulated signal on each pixel. Pixels are reset only when the user chooses to do so. CCDs on the other hand transfer the charge, therefore the accumulated signal is lost every read.
3. ELIS-1024 provides a Shutter Control (SHT). When closed, all the pixels are simultaneously sampled while integrating. Once opened, the last integrated value of all the pixels are held (sampled) on each pixel's associated integrator circuit. This is a 'Full Frame Shutter'. CCDs simultaneously transfer the charge form each pixel into a 'readout register' which is then serially read out. This is also a 'Full Frame Shutter' however the data on each pixel is then lost.
4. The ELIS-1024 allows readout of the integrated signal while the shutter is opened or closed. Therefore the pixel array can be readout while integrating or not. This enables adaptive exposure control and/or non-destructive read control.
5. The ELIS-1024 is capable of very short integration times, sub 1 microsecond is achievable.

One of the most useful features of the ELIS-1024 sensor is the ability to readout the image sensor array non-destructively. The sensor has a mode of operation called ***Non-Destructive Readout (NDRO)***. The timing for this is shown below. Using this mode allows the pixel values held on the sample and hold circuit to be reread multiple times. By averaging multiple reads together the overall S/N can be improved. Refer to the block diagram for the sensor shown in Figure 1 for details.

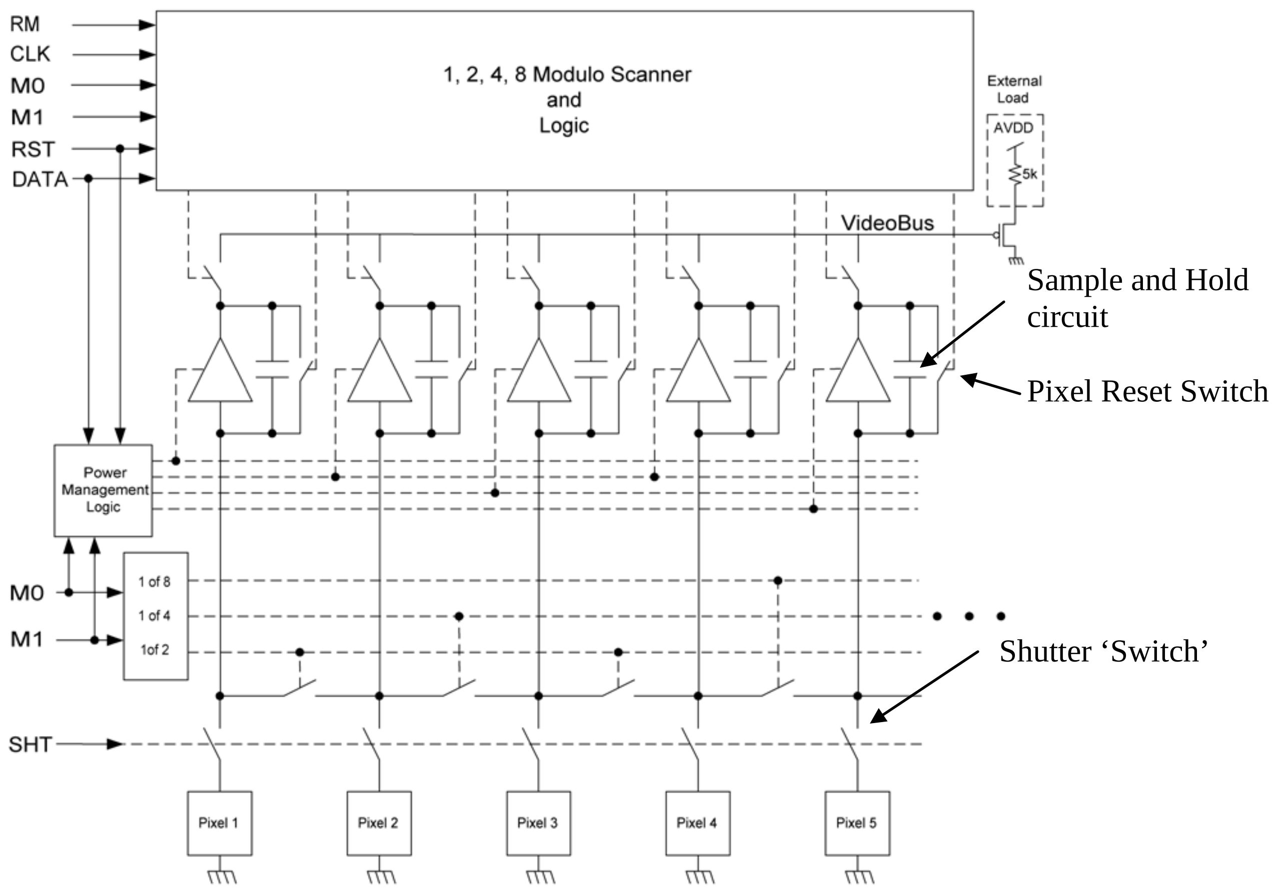

Figure 1: - Block diagram of ELIS-1024 sensor showing the Shutter circuit controlled by the SHT input.

The SHT input can be thought of as controlling a simple switch which connects the pixel photodiode to the sample and hold circuit. This switch is held closed during signal integration and then opened to capture or hold the last integrated signal form the pixel. Note that the pixel itself may continue to integrate, however as long as the SHT switch is opened, no further change in signal can be detected (unless of course SHT is closed again).

To perform NDRO, the sensor must be set to Frame Mode by setting the RM input low. After signal integration, RST and SHT are held low. By firing DATA multiple times, one can capture multiple frames of the sampled pixel values. Note that this mode works no mater what resolution is selected (via M0 and M1 signals – see specification for details). Then averaging these frames together reduces random noise accordingly. Figure 2 below shows this timing.

To maximize overall performance and signal to noise the following steps should be done.

1. Allow system temperature to stabilize.
2. Capture a 'dark reference' averaged frame.
3. Capture video averaged frame.
4. Subtract the dark reference frame from the signal frame.

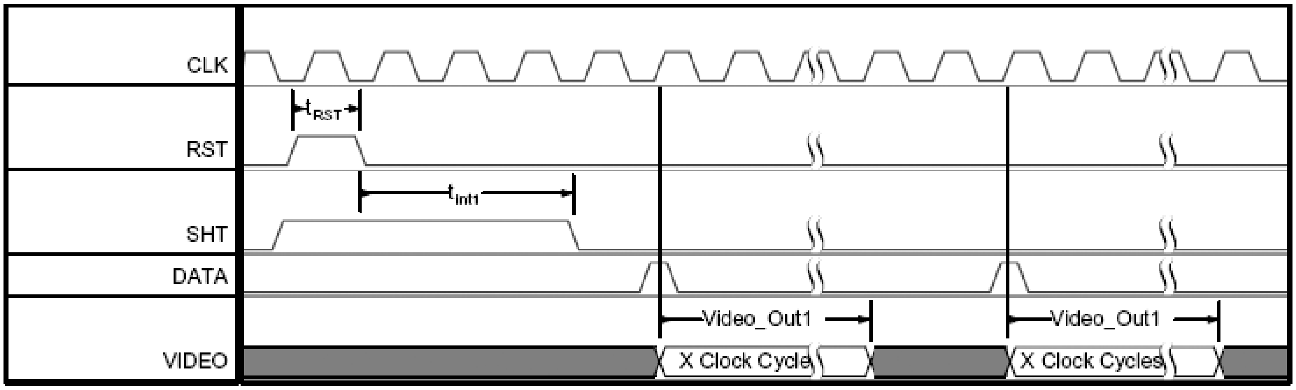

Figure 2: NDRO Timing diagram showing non-destructive readout after the shutter is opened. Adaptive exposure is achieved by simply keeping the SHT signal high and strobing the DATA signal for readout.

1. Temperature stabilize the system.
   Although this is not required, if one wants the absolute best system performance than the system temperature should be stabilized.
2. Capture a 'dark reference' averaged frame. The need to do this step is dependant on the application. If one is studying absolute value data then is should be performed. If one is looking for relative changes within the same dataset and does not care about absolute values, this step can be skipped. Perform this step by ensuring the sensor is in total darkness. Using the exact same timing and controls signals to perform this step as are used to capture signal data. Follow the timing shown in the figure above. If collecting 100 samples of live data, then collect 100 samples of dark data and average. Using the following simple equation, average the accumulated samples accordingly.

   Assume the readout for the *i*th iteration is x_i and the total number of readout frames is n, the averaged readout is

   $$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

   Thus the energy level of independent temporal random noise reduces to 1/*n* of that of the single readout. By this way, one can achieve the higher SNR and larger dynamic range.

3. Capture your video or sample data with your light again using the exact same timing as done in step 2 above.
4. Subtract the averaged data from step 2 from the averaged signal data acquired in step 3.

Figure 3 below is a sample video captured from our Line Scan Demo kit with ELIS set for NDRO mode. This image is 100 lines of sampled video (100 frames). In this specified example, the noise level of signal pixel is 130mV, while the noise level reduces to 70 mV after only averaging just 16 of the frames.

Figure 3 - 100 Sample Frames Captured in NDRO mode

ADAPTIVE EXPOSURE MODE:

Although not explicitly mentioned in the datasheet, the sensor can be readout while integrating to maximize signal and/or perhaps prevent pixel saturation.

By keeping the SHT signal High (SHT switches are closed) the pixel value is continually sampled. Strobing the DATA signal will cause a frame to be readout Non-Destructively – while the pixels are accumulating. This is useful to maximize signal levels prior to opening SHT and performing signal averaging via normal NDRO.

COMBINED MODES:

Further system usefulness can be had by combining both ADAPTIVE and NON-DESTRUCTIVE modes with some additional host software. Because the pixels in the CMOS sensor can take a very large amount of light overload (does not typically bloom) compared to a CCD, the user has many other options for reading out the array to capture very weak signals and bright signals in the same dataset.

For example, by operating the sensor in ADAPTIVE mode, capturing and saving each frame, it is possible for the system to monitor each pixel during exposure to wait for individual pixels to reach near saturation. The system then could average the signals of all previous reads for that pixel (to greatly reduce random noise per the method described above) and store that averaged pixels value with it's associated integration time. The system can continue to do this for other pixels to continue to build signal levels for other pixels that may not have as strong a signal on them. Then the combined data set of averaged integrated values with associated integration time can be very useful, especially for Spectroscopy applications.

Appendix：Sensitivity Analysis of Silicon Sensors

All silicon imaging sensors (CCD &CMOS) convert the optical photons to output voltage. To compare the performance of different sensor, people use the term ‘sensitivity’.

Multiple definitions exist for the sensor’s sensitivity. A common definition is defined as ‘output voltage per incident optical energy density’ which is in the unit ‘Volts/lux.s’ or ‘volts/(uj/cm^2)’ . In some documents, this term is also named as ‘responsivity’.

Consider sensor A with sensitivity 2 volts/lux-s and sensor B with sensitivity 16 volts/lux.s. Literally, sensor B is ‘better’ than sensor A. However, if a 10x amplifier is connected to sensor A, output A is 10 times larger, and sensor A has higher ‘sensitivity’ than sensor B. What’s more, a sensor’s performance can be unlimited improved by modifying the output amplifier!

This is not true even without the physical bound limits (e.g. maximum and minimal output voltage). All real engineered products suffer from noise. In practice, we concern on the meaningful signals instead of raw signal.

If two sensors are made by the same technology and have the same level of noise, their performance may be compared using their responsivity to the photons. Unfortunately, noise levels of most sensors are quite different. Thus, the concept ‘sensitivity / responsivity’ only is not enough to describe meaningful sensitive performance of a sensor. We should also count the noise level when we evaluated a sensor’s feature.

For this purpose, the term **Signal-to-noise ratio** (**SNR**) of a sensor is considered. SNR is defined as the power ratio between a signal and the background noise. For the image sensor, its SNR can be empirically measure as the ratio of output’s mean value to its standard deviation.

For a typical CCD linear sensor, the sensitivity (responsivity) is 200 Volts/lx-s and SNR is about 45dB. As a comparison, the sensitivity of Panavision Imaging’s ELIS-1024 CMOS sensor is 0.34Volts/lx-s with over 65dB SNR. At the same incident light level, the CCD sensor has greater raw output than ELIS. To achieve the same output level, one can simply furnish a high-quality amplifier.

However, due to the higher SNR, ELIS-1024 has smaller noise level even its output is amplified to the same level as the CCD sensor. That is, for ELIS, the detectable change of meaningful output is smaller. In other words, ELIS can detect the smaller light change than the CCD sensor **–** ELIS is more sensitive!

From engineering point, one can easily design two imaging systems for these two sensors, such that two systems have the same output level for the same light intensity. However, the one with higher SNR sensors can detect the smaller meaningful output change. Thus, it is more sensitive.

Hence, to evaluate the meaningful sensitivity performance of an imaging sensor, both features ‘**Sensitivity** ‘and ‘**SNR**‘should be analyzed.